Rookery Bay
National Estuarine Research Reserve

Research

The Reserve's Research program provides the scientific information necessary to support an adaptive management strategy for conservation of natural biodiversity for the area managed by the Reserve. This strategy entails 1) identifying areas of scientific uncertainty, 2) planning and conducting field experiments to test hypotheses related to real-world management strategies, 3) exporting this information to environmental managers and decision makers, and 4) recommending improved management strategies based on the results of these experiments. A primary function of the Research program is to develop and monitor indicators of natural biodiversity at the levels of watershed, community, population and organism. This science-based hierarchical approach is necessary to more effectively manage the Reserve's natural resources and assess, prioritize and improve the effectiveness of future habitat restoration projects. To be successful, these activities are closely coordinated with the Reserve's Resource Management, Public Access and Education programs.

Contents

History of Research Program

The earliest record of research for the Rookery Bay area are water quality and red tide studies (Finucane & Dragovich, 1959; Dragovich & Finucane, 1961; Dragovich, 1963). Ten years later, a small marine laboratory was established, funded through CSF. At this time, staff and community volunteers conducted baseline studies of water quality, hydrodynamics and fish populations. The results of these studies were published as a series of reports (Lee & Yokel, 1973; Clark, 1974; Yokel 1975 a, b & c). Lugo et al. (1973), Lugo & Snedaker (1973 & 1975), Poole and Lugo (1973), Poole et al. (1975 & 1977), Snedaker & Poole (1973), and Wanless (1974) conducted additional investigations on mangrove forest ecology and productivity and nearshore sedimentological processes.

In the late 1970's, a series of reports were generated in support of the draft environmental impact statement for the Deltona Corporation's residential development in wetlands near Marco Island. These reports catalogue a variety of ecological measurements including nutrient cycling, watershed hydrology, fish and macroinvertebrate abundance, floral surveys and water quality (Tabb et al. 1977; Weinstein et al., 1977; Heald, 1978, 1979 & 1981; Below & Kahl, 1979; Carpenter & Larsen, 1979; Courtney, 1979; Daddio & van der Kreeke, 1979; Finan, 1979; Finan & Finan, 1979; Huber & Brezonik, 1979 & 1981; Larsen, 1979). Since 1974, RBNERR's Audubon Society Warden/Biologist, Mr. Theodore Below, has continued monitoring and recording wading and shorebird numbers and fledgling success at several important habitats.

In 1978, the area was designated as a National Estuarine Research Reserve. The DEP assumed responsibility for the Reserve's research program. Studies by on site staff and visiting investigators continued to expand the Reserve's knowledge base (Twilley, 1982,1985 &1988; Twilley et al., 1986; Thoemke and Gyorkus,1988 a & b).

In 1990, in response to recommendations from a NOAA site review, DEP established a research coordinator position with initial funding support from NOAA. The Reserve developed additional laboratory facilities and research support capabilities, including water quality monitoring equipment, research vessels and a weather station. RBNERR established a Research Advisory Committee to provide input on research goals and direction. The Reserve's initial bimonthly water quality program has since been upgraded to allow for continuous monitoring of physical (temperature, turbidity and depth) and chemical measurements (pH, dissolved oxygen, and salinity).

In August 1992, Hurricane Andrew swept across South Florida and exited to the Gulf of Mexico approximately 35 miles south of Rookery Bay in Everglades National Park, causing extensive damage to mangrove forested wetlands. The Reserve played a key role, in cooperation with federal and State agencies, in conducting research to assess impacts of this catastrophic event (Smith, 1993; Nalley et al., 1997). RBNERR has recently expanded monitoring of water quality, and fish and macroinvertebrate populations in the Ten Thousand Islands ecosystem, to establish baseline conditions prior to planned restoration of watershed sheetflow to the area.

CORE OBJECTIVES

- Conduct and facilitate research projects to identify watershed scale flowways and effective stormwater management strategies to reduce nonpoint source pollutant loading and restore natural sheetflow. The area connecting the Henderson Creek system to the Belle Meade watershed and the agricultural areas in the lower Belle Meade watershed will be priority targets of this research initiative.
- Continue long-term monitoring and facilitate regional research to examine estuarine habitat quality, integrating water quality and biological monitoring, to provide baseline information needed to set goals and assess the outcome of hydrologic restoration and pollution abatement programs with emphasis on the Reserve's watershed.
- Conduct and facilitate research to identify minimum flows and effective water management strategies to conserve natural estuarine biodiversity for the Reserve's watershed including Water Management District 6 (Lely Canal), Belle Meade, Fakahatchee and Southern Golden Gate Estates.
- Continue long-term monitoring and facilitate additional research examining the relative abundance of stenohaline and euryhaline estuarine species within habitats of varying degrees of watershed alteration to assess the effectiveness of various flowway management strategies at restoring natural salinity patterns.
- Continue the long-term monitoring of pesticide sensitive species and facilitate additional research to assess the impact of nonpoint source pesticide contamination from watershed agricultural activities.
- Continue the long-term monitoring of pesticide sensitive species and facilitate additional research to assess the impact of nonpoint source pesticide contamination from watershed mosquito

control activities.
- Develop and maintain a watershed GIS incorporating all available data layers regarding wetland, flowways, critical habitats, conservation areas, archaeological sites, and landuse with annual updates to guide restoration efforts and to inform the public and coastal managers of the interactions of these processes.
- Continue the long-term monitoring of pesticide sensitive species and facilitate additional research to assess the impact of nonpoint source pesticide contamination from watershed residential development.
- Develop and maintain a terrestrial habitat GIS including data layers representing the distribution of invasive species and native habitats to assist in the planning and assessment of the Reserve's exotic control strategies and prescribed burn program.
- Develop an annual GIS to assist in prioritizing the control of invasive species by identifying habitats known to be sensitive to exotic infestations (i.e. accreting shorelines, pine flatwoods, nesting sea turtle and shorebird habitats) or representing unique ecotypes (i.e. coastal hammocks, scrub).

Current Research

Projects

Water quality

Fisheries inventory

Macroinvertebrate inventory

Turtles

Bird monitoring

Harmful Algal Blooms (HAB)

Several long-term monitoring projects make up the foundation of the research department at RBNERR. Although special high-interest research projects are often funded and staffed by temporary Reserve staff, these monitoring projects are priorities for meeting the core objectives of undersdtanding natural versus human induced environmental changes.

The projects presented here represent key efforts towards meeting research goals as established in the 2000-2005 management plan, and cover these core objectives:

- long-term monitoring to examine estuarine habitat quality, integrating water quality and biological monitoring, to provide baseline information needed to set goals and assess the outcome of hydrologic restoration and pollution abatement programs
- long-term monitoring of the relative abundance of stenohaline and euryhaline estuarine species within habitats of varying degrees of watershed alteration to assess the effectiveness of various flowway management strategies at restoring natural salinity patterns.
- long-term monitoring of pesticide sensitive species to assess the impact of nonpoint source pesticide contamination from watershed agricultural activities, mosquito control activities, and residential development.
- examine the factors influencing sea turtle nest selection and hatchling success for the area managed by the Reserve.

- identify human-induced habitat changes that adversely affect natural biodiversity to guide restoration strategies and public use policy

Water Quality

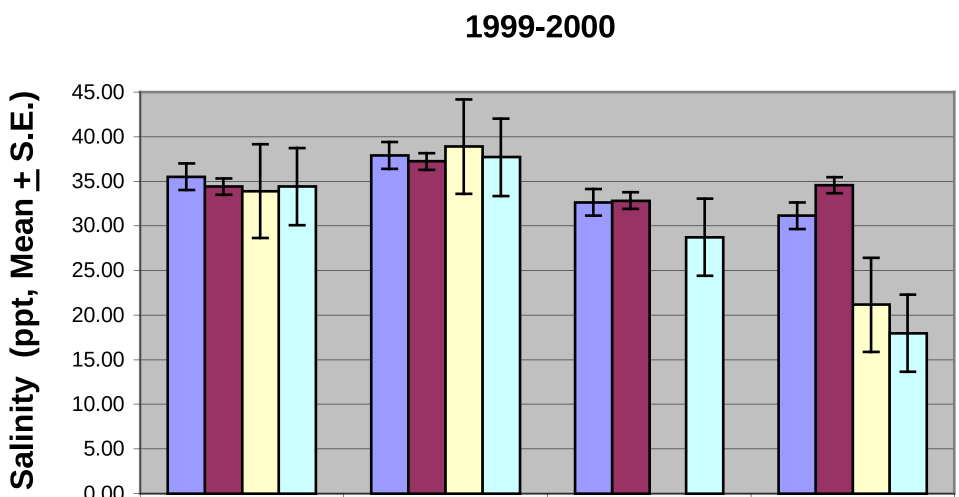
The record of long-term physicochemical measurements for the surface waters managed by the Reserve began in 1970 (Yokel, 1975). Differences in sample locations, analytical methods and reporting techniques allows only for gross generalizations to be made regarding trends in these datasets. Christensen (1998) analyzed monthly rainfall, secchi depth, surface and bottom dissolved oxygen, turbidity, temperature and salinity data collected by the Reserve's staff at seventeen fixed stations throughout the Rookery Bay Aquatic Preserve from 1986 to 1992.

Presently, the Reserve's staff maintains four continuous monitoring stations, contributing to the National Estuarine Research Reserve system-wide monitoring program (SWMP) and jointly funded by NOAA and the State of Florida. These stations record temperature, salinity, dissolved oxygen, pH, depth and turbidity at one-half hour intervals. Two stations, lower Blackwater River and lower Henderson Creek, have been collecting data since April 1996. Two additional stations, Faka Union Bay and Fakahatchee Bay were established in 1999 to expand the area studied by this monitoring program. All four stations were located in the mesohaline portion of each estuarine system in water having similar depths and dry season salinity. The primary purpose of the Reserve's current monitoring program is to supplement the biological data being collected for assessing hydrologic watershed restoration projects. This recent monitoring strategy lacks the spatial coverage of previous efforts but collects data on time scales previously unavailable and is providing insight into biologically significant short-term changes in physicochemical conditions.

Salinity

The estuarine salinity of the Reserve responds to tides, rainfall and canal management. In a two year study, from1970 to 1972, Yokel (1975) found a mean salinity for Henderson Creek of 27.8 ppt. Carter et al. (1973) noted that during high runoff periods the flow out of the Faka Union Canal lowered the salinity of the eastern section of Fakahatchee Bay as much as 10 ppt in the western sections of the Bay. Christensen (1998) reported that it was not uncommon to find hypersaline conditions, particularly in March and April, in the Reserve's monthly dataset collected from 1986 to 1992. Christensen (1998) also reported that Henderson Creek was the station with the greatest variability in salinity, turbidity and depth. In general, the minimum salinity occurred in September and the maximum salinity occurred in May (Christensen, 1998). In an analysis of one-year (1998) of continuous salinity data from upper Blackwater River, Wenner, et al. (2001) also found that minimum salinity occurred in September (1.4 ppt) and maximum salinity occurred in May (36 ppt). These researchers found large (5-15 ppt) biweekly fluctuations in salinity at this station. Analysis results for the upper Henderson Creek dataset revealed even greater fluctuations in salinity (= 15 ppt) during episodic events, presumably as a result of storm runoff or water being released from the weir at this estuary's headwaters (Wenner et al., 2001) . Data collected by the Reserve's staff in lower Henderson Creek, lower Blackwater River, Faka Union Bay and Fakahatchee Bay also indicate that minimum regional salinity occur in the late rainy season with Faka Union Bay exhibiting significantly lower values (Nalley et al., 1997; Shirley et al., unpublished data; Figure 1). In addition, greater salinity stratification was recorded in Faka Union Bay than in Blackwater River, Gullivan Bay, Pumpkin Bay or Fakahatchee Bay (Nalley et al., 1997).

The data for the existing stations has been analyzed by year, season and location. Season is categorized as late rainy (September through November), early dry (December through February), late dry (March through May) and early rainy (June through August) based on fifty years of NOAA climate data (www.ncdc.noaa.gov) collected at the Naples Pier and fourteen years of salinity data collected at the Reserve.



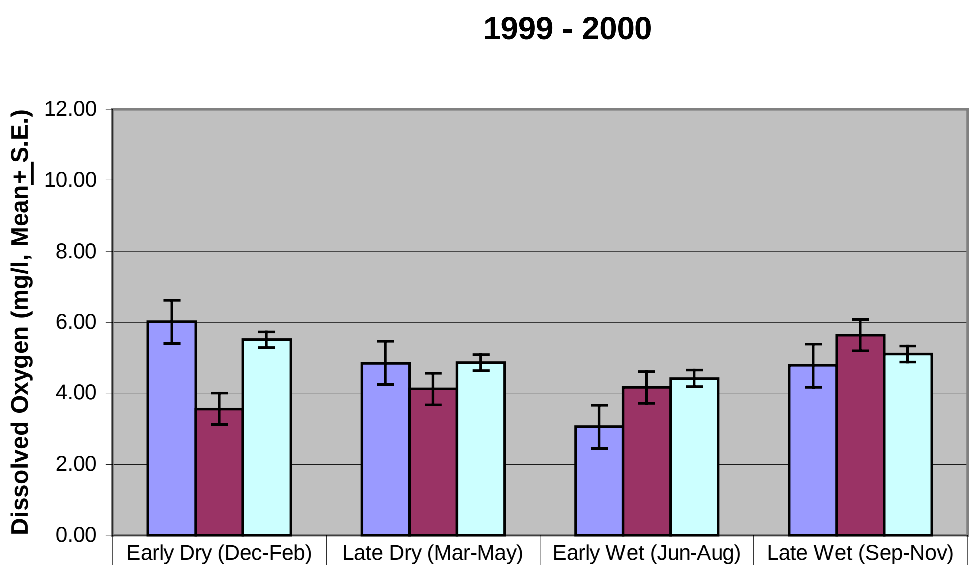
	Early Dry (Dec-Feb)	Late Dry (Mar-May)	Early Wet (Jun-Aug)	Late Wet (Sep-Nov)
Blackwater River	35.50	37.88	32.63	31.18
Henderson Creek	34.41	37.22	32.85	34.55
Fakahatchee Bay	33.90	38.90		21.17
Faka Union bay	34.42	37.72	28.71	17.98

Season

Figure 1. The average salinity (ppt, ± standard error) at four continuous monitoring stations within the Reserve.

Dissolved Oxygen

Yokel (1975) measured oxygen concentrations within Henderson Creek and found a daytime range of 5.5 to 6.3 ppm and a nighttime range of 4.5 to 4.9 ppm and concluded that oxygen was not a limiting factor. Van de Kreeke (1973) found predawn dissolved oxygen concentrations within Johnson Bay to be consistently below 4 ppm and as low as 0.8 ppm. This researcher also found that 68% of the values recorded from Johnson Bay were below 4 ppm and 35% of the values were below 2 ppm. Yokel (1975) found dissolved oxygen concentrations to be negatively correlated to rainfall and positively correlated with salinity, and Christensen (1998) found that bottom dissolved oxygen concentrations were negatively correlated with temperature. In Christensen's analysis, Henderson Creek was found to have the lowest recorded oxygen concentrations of the areas monitored. In general, minimum oxygen levels occurred in August and maximum concentrations occurred in March (Christensen, 1998). Shirley and Haner's (1997) continuous oxygen data indicated that lowest mean levels (4-4.6 ppm) occurred between 7 to 9 am and maximum mean levels (5.3 to 6.9 ppm) occurred from 5 to 8 pm. Wenner's et al. (2001) analysis of the continuous dataset from upper Blackwater River reported that dissolved oxygen (as percent saturation) was greatest in March to June and least in July to October. Preliminary analyses of recent continuous monitoring by the Reserve's staff within the lower Blackwater River, lower Henderson Creek, Faka Union Bay and Fakahatchee Bay indicates that consistently greater dissolved oxygen concentrations (as ppm) occur in the late rainy season, although site-specific influences are apparent (Shirley et al., unpublished data; Figure 2).



	Early Dry (Dec-Feb)	Late Dry (Mar-May)	Early Wet (Jun-Aug)	Late Wet (Sep-Nov)
Blackwater River	6.01	4.85	3.06	4.78
Henderson Creek	3.56	4.12	4.16	5.64
Faka Union Bay	5.50	4.86	4.42	5.10

Season

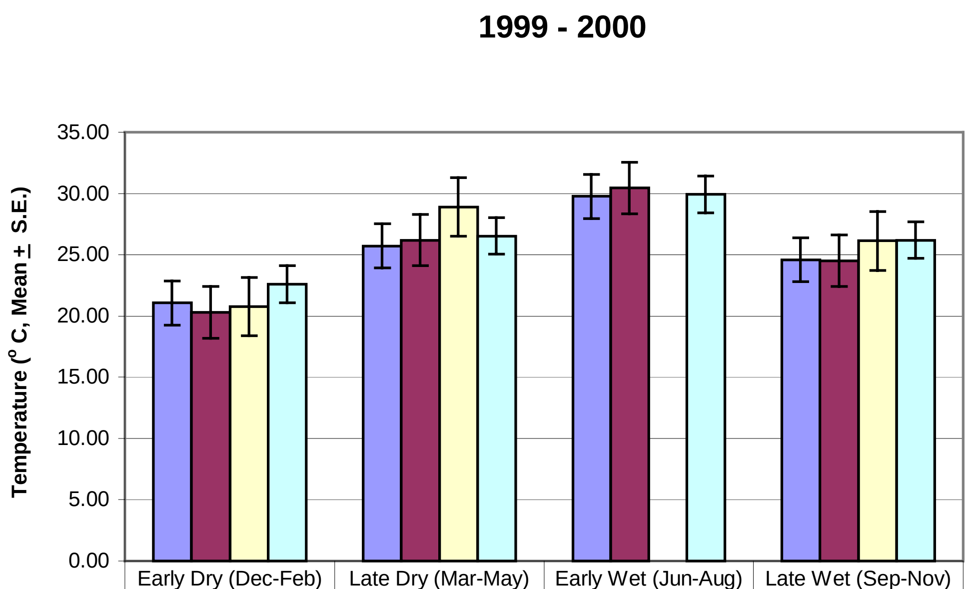
Figure 2. The average dissolved oxygen concentration (ppm, ± standard error) at three continuous monitoring stations within the Reserve.

Temperature

In general, based on six years of data collected by the Reserve's staff from 1986 to 1992, minimum mean temperatures occurred in December and maximum mean temperatures occurred in July (Christensen, 1998). Similar results were found in an analysis of continuous temperature data for upper Henderson Creek and upper Blackwater River (Wenner et al., 2001). This is also consistent with recent observations made by the Reserve's staff (Nalley et al., 1997; Shirley et al., unpublished data, Figure 3).

pH

In an analysis of six years of data collected by the Reserve's staff at seventeen fixed locations sampled from 1986 to 1992, Chistenson (1998) found pH to be positively correlated with dissolved oxygen, with the lowest pH values reported during August. This is consistent with recent observations made by the Reserve's staff (Shirley et al., unpublished data, Figure 4), although site-specific effects are apparent.



	Early Dry (Dec-Feb)	Late Dry (Mar-May)	Early Wet (Jun-Aug)	Late Wet (Sep-Nov)
Blackwater River	21.06	25.71	29.76	24.58
Henderson Creek	20.29	26.18	30.45	24.50
Fakahatchee Bay	20.77	28.88		26.11
Faka Union	22.59	26.53	29.93	26.19

Season

Figure 3. The average temperature (°C,± standard error) at four continuous monitoring stations within the Reserve.

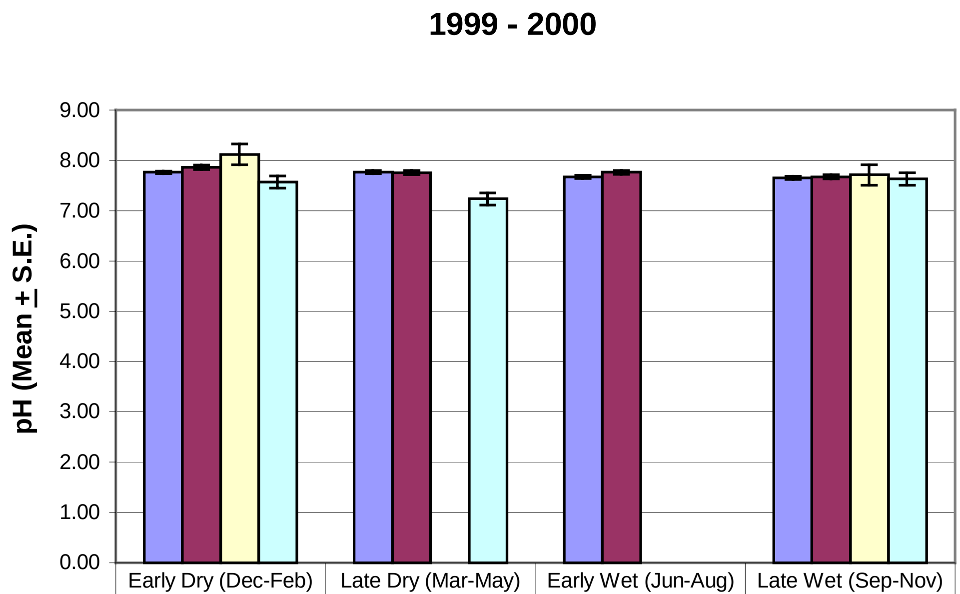
Turbidity

In general, the analysis of six years of monthly daytime water quality monitoring from 1986 to 1992 within the Rookery Bay Aquatic Preserve, showed that minimum turbidities occurred in September and maximum turbidities occurred in February (Christensen, 1998). Present monitoring of continuous turbidity values for lower Blackwater River also indicates that maximum turbidity occurs in the dry season and minimum values occur during the wet season (Shirley et al., unpublished data, Figure 5).

Nutrients

Phosphorus

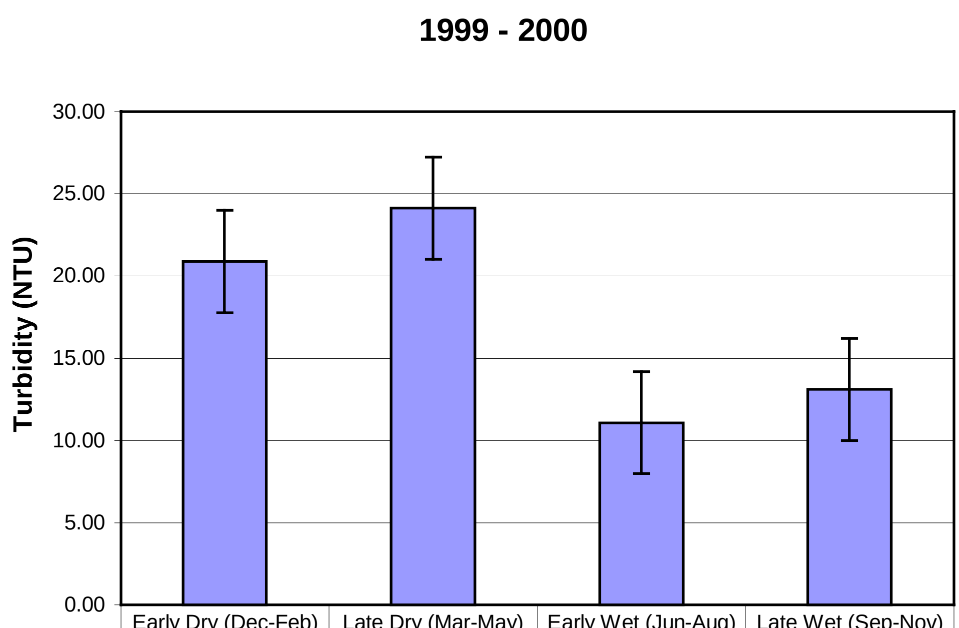
Yokel (1975) reported mean monthly total phosphate concentrations for lower Henderson Creek ranging from 0.041 to 0.07 ppm in a study conducted from 1970 to 1972. Similarly, Weinstein et al. (1977) analyzed data from samples collected from Henderson Creek and found total phosphate concentrations ranging from 0.017 to 0.111, with a mean of 0.04 ppm. Carpenter (1973) sampled Johnson Bay and nearby mangrove creeks during April, June and August 1973 and found total phosphate to vary from 0.047 to 0.076 ppm. Schaiberger (1973) reported total phosphate concentrations ranging from 0.079 to 0.083 in surface water samples collected from Johnson and Addison Bay. Thoemke and Gyorkos (1987) reported a mean phosphate concentration of 0.0067 ppm in samples collected from Hall Bay, Henderson Creek and Rookery Bay. In a statistical analysis of the Reserve's nutrient dataset (1986 to 1992), Christensen (1998) found an average total phosphate concentration of 0.0845 ppm for twelve fixed stations sampled monthly. During April 1996 to March 1997, Shirley and Haner (1997) collected monthly surface water samples in Henderson Creek during ebb tides that coincided with storm events at a site close to Yokel's Henderson Creek station. These



	Early Dry (Dec-Feb)	Late Dry (Mar-May)	Early Wet (Jun-Aug)	Late Wet (Sep-Nov)
Blackwater River	7.76	7.77	7.67	7.65
Henderson Creek	7.86	7.76	7.76	7.67
Fakahatchee Bay	8.12			7.71
Faka Union Bay	7.57	7.24		7.63

Season

Figure 4. The average pH (standard units, ± standard error) at four continuous monitoring stations within the Reserve.



	Early Dry (Dec-Feb)	Late Dry (Mar-May)	Early Wet (Jun-Aug)	Late Wet (Sep-Nov)
Blackwater River	20.89	24.12	11.07	13.10

Season

Figure 5. The average turbidity (NTU, ± standard error) at one continuous monitoring station within the Reserve.

“worst-case” samples were found to have total phosphate concentrations ranging from 0.06 to 0.075 ppm.   More recent data (Jones et al. 1997), indicates that samples collected from the Ten Thousand Islands during 1992 to 1997 have total phosphorus concentrations ranging from 0.002 to 0.343 (median = 0.087 ppm). Monitoring conducted monthly by the Collier County Pollution Control and Prevention Department found mean phosphate concentrations in upper Henderson Creek during 1998 and 1999 to range from 0.01 to 0.04 ppm (Dugan, 2000).

In his 1970 and 1972 study, Yokel (1975) found no seasonal trends in total phosphate concentrations. Thoemke and Gyorkos (1987) found greater phosphate concentrations in the early rainy season with the lowest concentrations occurring in late rainy season. These researchers concluded that biological uptake, as suggested by increasing chlorophyll a concentrations, was responsible for this seasonal pattern. Gibson (1997) also found this pattern for surface water samples collected from Goodland Bay and the Faka Union Canal. Thoemke and Gyorkos (1987) reported a high overall ratio of dissolved inorganic nitrogen to dissolved inorganic phosphate and suggested that phosphate is limiting in the Rookery Bay system. The analysis by Christensen (1998) also supports this conclusion regarding seasonal changes in phosphate and chlorophyll a concentrations; however, this author concludes, based on Redfield Ratios, that the Reserve’s open water habitat tends towards nitrogen limitation and becomes phosphorous limited only in the late rainy season.

Nitrogen

Surface water nitrogen, as nitrite, nitrate, ammonia and total nitrogen, has been monitored within the estuaries managed by the Reserve since 1971 (Weinstein, 1977). Weinstein found respective nitrate, nitrite, and ammonia concentrations of 0.003 to 0.067 (mean = 0.017 ppm), 0.0 to 0.002 (mean = 0.001 ppm) and none detected to 0.107 (mean = 0.038 ppm). Carpenter (1973) sampled Johnson Bay and nearby mangrove creeks during April, June and August 1973 and found nitrate ranging from 0.0062 to 0.248 ppm, nitrite ranging from 0.0092 to 0.0138 ppm and ammonia ranging from 0.037 to 0.041 ppm. Thoemke and Gyorkos (1987) sampling in June through December 1984 in Henderson Creek, Hall Bay and Rookery Bay and found ammonia concentrations ranging from 0 to 0.046.   The mean nitrate (0.064 ppm) and nitrite (0.0029 ppm) concentrations measured by Thoemke and Gyorkos (1987) were also within the range found by previous researchers.   In a statistical analysis of the Reserve’s nutrient data collected from 1986 to 1992, Christensen (1998) reported mean nitrate, nitrite and ammonia concentrations of 0.066, 0.028 and 0.022 ppm, respectively for twelve fixed stations located throughout the Rookery Bay Aquatic Preserve. Christensen’s (1998) analysis indicates an overall increase in surface water nutrients, peaking in 1988, with a sharp decline thereafter.   Water samples collected in Henderson Creek from April 1996 to March 1997 associated with storm events had ammonia concentrations ranging from 0.025 to 0.13 ppm (Shirley and Haner, 1997).   Jones et al. (1997) reported a range of nitrate, nitrite and ammonia concentrations of none detected to 1.178 (median = 0.042 ppm), none detected to 0.35 (median = 0.008 ppm) and 0.001 to 1.347 (median = 0.024 ppm) respectively from samples collected from the Ten Thousand Islands.   Monitoring conducted monthly by the Collier County Pollution Control and Prevention Department found mean nitrate, nitrite and ammonia concentrations in upper Henderson Creek during 1998 and 1999 to range from 0.01 to 0.1 ppm, 0.01 to 0.01 ppm and 0.01 to 0.26 ppm (Dugan, 2000).

Thoemke and Gyorkos (1987) suggested that surface water nitrate concentrations peak when rain and tidal water flows through mangrove forest habitats and when high winds resuspend bottom sediments. Christensen (1998) also found a significant positive correlation between turbidity and nutrient concentrations, indicating that sediment resuspension may be a primary source of nutrients. Theomke and Gyorkos (1987) reported that nitrate was the dominate form of nitrogen during the rainy season, whereas in October, all stations, except mid-Henderson Creek, shifted dominance to ammonia.

Bacteriological Monitoring

There is a record of fecal coliform monitoring for the estuaries managed by the Reserve, often associated with shellfish harvesting surveys, from 1982 (Lim, 1983) to 1992 (Seagle, 1992). Lim (1982) collected bimonthly samples at three stations in Naples Bay, Rookery Bay and Fakahatchee Bay from September 1982 to July 1983 . This study found total and fecal coliform counts to be greater in Naples Bay and Rookery Bay than in Fakahatchee Bay. Lim (1982) also found that bacterial counts progressively increased going from coastal to inland stations. Nutrient levels were found to be similar in all three bay systems and not influenced by season. Lim (1982) also reported detecting *Vibrio cholerae*, *Vibrio parahaemolyticus* and *Salmonella* in thirty-three percent of the samples. *Vibrio* was detected in all three bay systems and *Salmonella* was only detected in Rookery Bay.

Seagle (1992) summarized fecal coliform data collected at twenty-six stations sampled in the Ten Thousand Island region from 1986 to 1992. In contrast to the previous study, Seagle (1992) found significant associations between fecal coliform counts and rainfall. Two stations, in the Faka Union Canal south of U.S. 41, exceeded the minimum probable number (mpn) standard. Barnett et al. (1989) assessed the condition of shellfish harvesting areas from Naples Bay south to Gullivan Bay. In this study, four stations were found to have high mpn values, Henderson Creek at the County Road 951 bridge, Naples Bay, Dollar Bay and Hill Bay. These researchers also found a significant association between fecal coliform counts and rainfall. Research using *E. coli* ribosomal RNA and multiple antibiotic resistance profiles indicated that humans were the primary source of fecal coliform bacteria in upper Henderson Creek (Tamplin,1997).

Algae: Red Tide

Finucane and Dragovich (1959) summarized the counts of *Gymnodinium breve* and associated oceanographic data from the west coast of Florida for studies conducted from 1954 to 1957. Dragovich (1963) provided a detailed species list of plankton, including *Gymnodinium breve*, and nutrient data for samples collected near the Naples pier from 1956 and 1957. The proceedings of the Red Tide Studies, Pinellas to Collier Counties, 1963-1966 (Florida Marine Research Institute, 1967) symposium included identification keys for dinoflagellates and diatoms, nutrient data, cell counts, salinity and temperature. Statistical analysis of the association of the physicochemical data and the occurrence of plankton species were not presented in these reports.

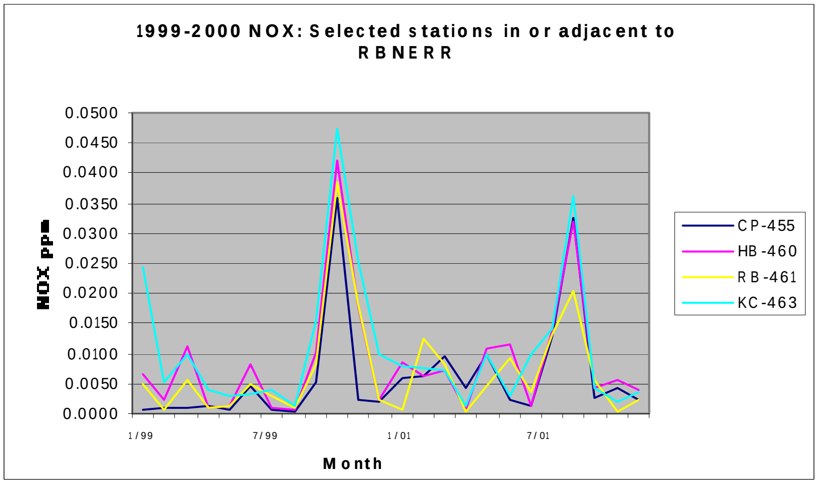
Monthly Profiles by Geographic Location

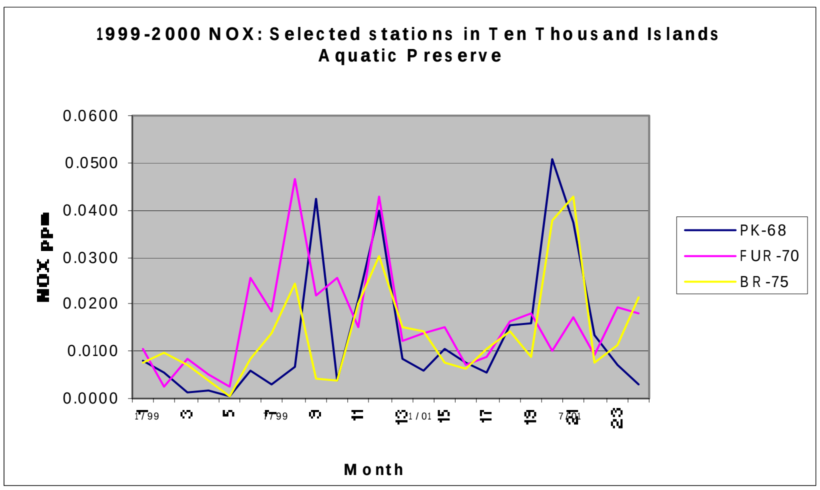
(Data were provided by the *Water Quality Monitoring Network* operated by the Southeastern Environmental Research Center, Florida International University, Miami, Florida, which is supported by SFWMD/SERC Cooperative Agreement #C-10244 and EPA Agreement #X994621-94-0.)

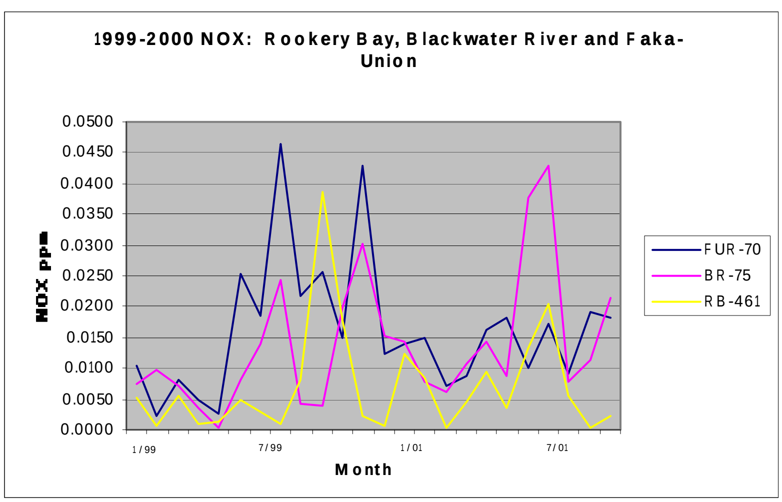
Data for the following graphs have been selected from a comprehensive set of water quality monitoring stations based on their geographic location compared to Rookery Bay. All stations chosen are either in or adjacent to Rookery Bay National Estuarine Research Reserve (RBNERR) or the Cape-Romano – Ten Thousand Islands Aquatic Preserves (10Ts AP) boundaries. Water quality parameters chosen for comparison are those most often correlated with the trophic state of the water body: inorganic nitrogen (NOx), ammonium (NH4), total phosphorus (TP), the ratio of nitrogen to phosphorus (TN:TP), chlorophyll *a* (Chl A), dissolved oxygen (DO), and salinity (SAL).

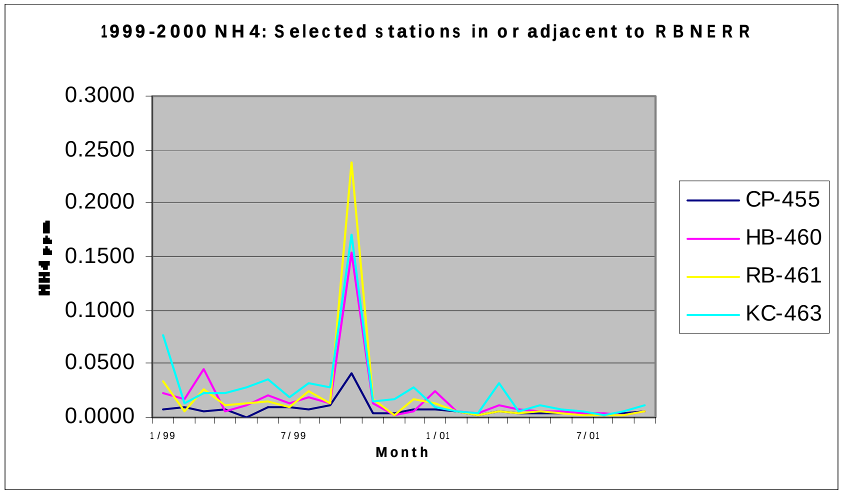
Three comparative graphs have been presented for each parameter. One compares stations selected from the 10Ts AP in the eastern portion of areas managed by RBNERR – the coastline that faces south. These areas receive runoff from the Picayune Strand and Seminole-Collier watersheds as well as from the wetlands south of US 41. The second compares stations along the western facing coastline and areas closest to and including Rookery Bay. These areas receive runoff from the Belle Meade and District VI watersheds as well as from the wetlands west and southwest of US 41. The third graph compares Rookery Bay profiles to Faka-Union Canal and Blackwater River illustrating differences and similarities between the two different geographic locations and three different water delivery systems. Other differences between these locations have been discussed in depth in another section.

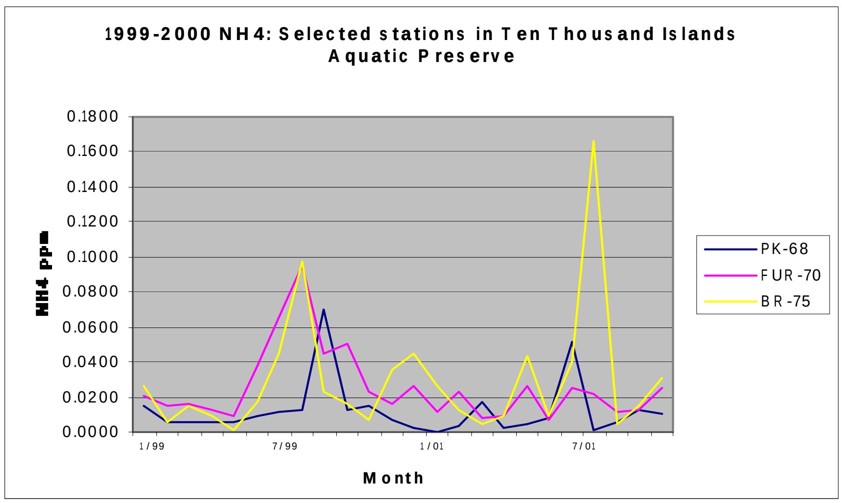
Key to stations: PK 68 – Panther Key; FUR 70 – Faka-Union Canal; BR 75 – Blackwater River; CP 4555 – Capri Isle Pass; HB 460 – Hall Bay; RB 461 – Rookery Bay; KC 463 – Key Island Channel.

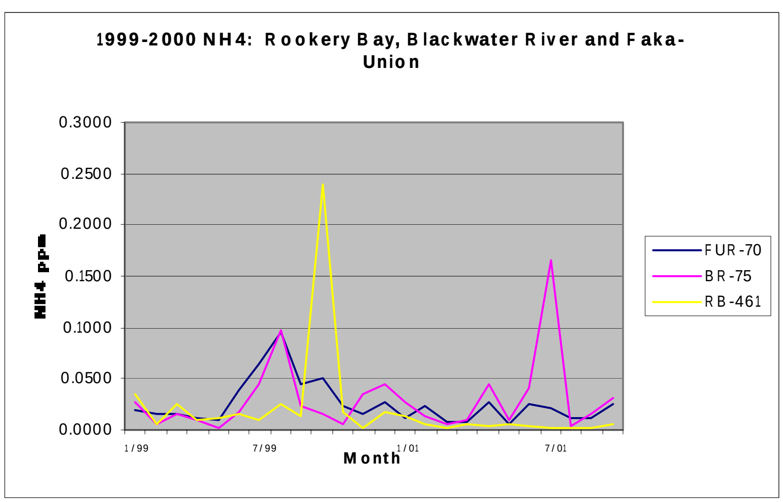


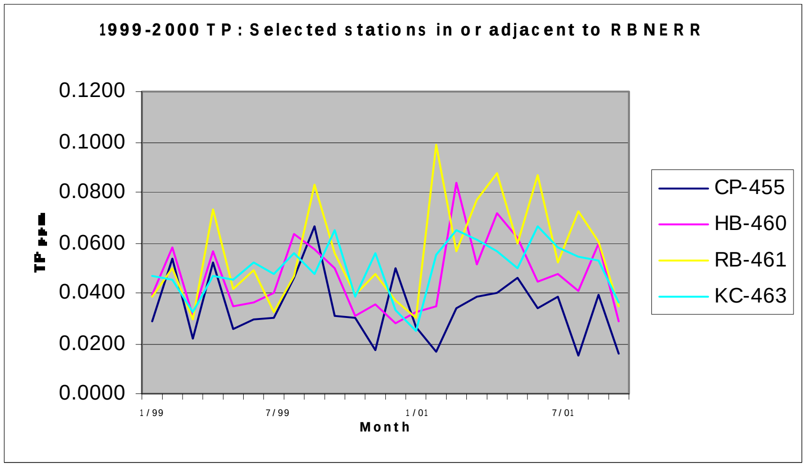


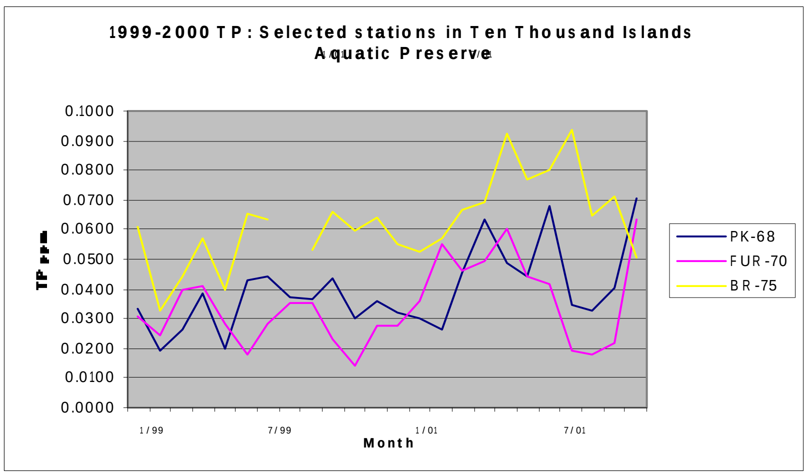


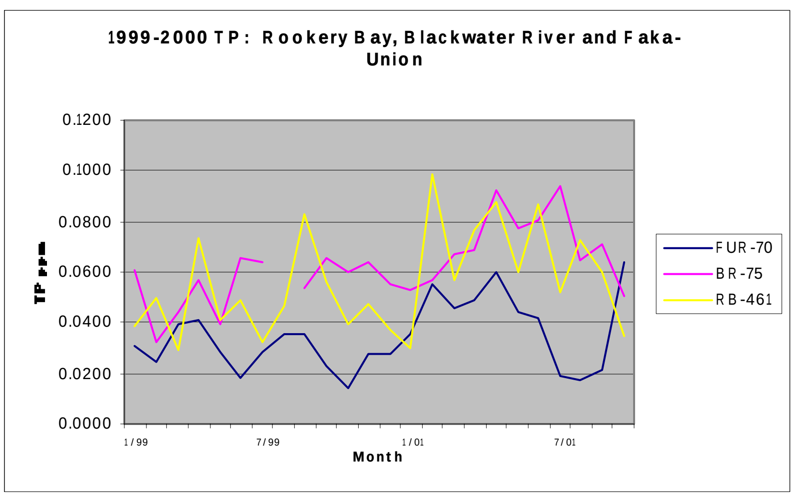

1999-2000 NH4: Selected stations in or adjacent to RBNERR
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
NH4 ppm
1/99
7/99
1/01
7/01
Month
CP-455
HB-460
RB-461
KC-463

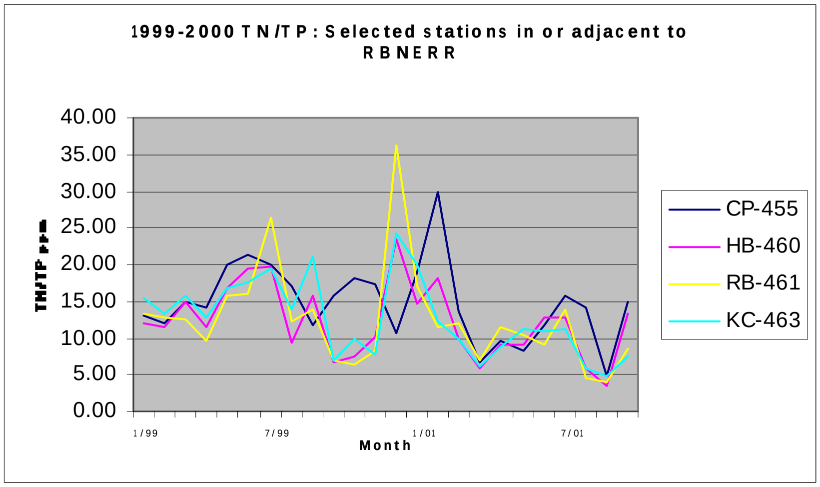

1999-2000 NH4: Selected stations in Ten Thousand Islands Aquatic Preserve
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
NH4 ppm
1/99
7/99
1/01
7/01
Month
PK-68
FUR-70
BR-75


1999-2000 NH4: Rookery Bay, Blackwater River and Faka-Union
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
NH4 ppm
1/99
7/99
1/01
7/01
Month
FUR-70
BR-75
RB-461


1999-2000 TP: Selected stations in or adjacent to RBNERR
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
TP ppm
1/99
7/99
1/01
7/01
Month
CP-455
HB-460
RB-461
KC-463


1999-2000 TP: Selected stations in Ten Thousand Islands Aquatic Preserve
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
TP ppm
1/99
7/99
1/01
7/01
Month
PK-68
FUR-70
BR-75


1999-2000 TP: Rookery Bay, Blackwater River and Faka-Union
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
TP ppm
1/99
7/99
1/01
7/01
Month
FUR-70
BR-75
RB-461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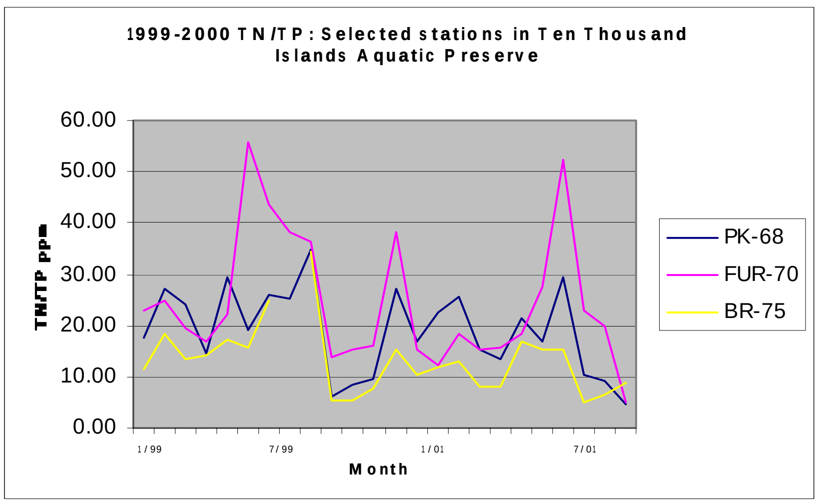
TN/TP ppm
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1/99
7/99
1/01
7/01
Month
CP-455
HB-460
RB-461
KC-463


1999-2000 TN/TP: Selected stations in Ten Thousand Islands Aquatic Preserve
TN/TP ppm
60.00
50.00
40.00
30.00
20.00
10.00
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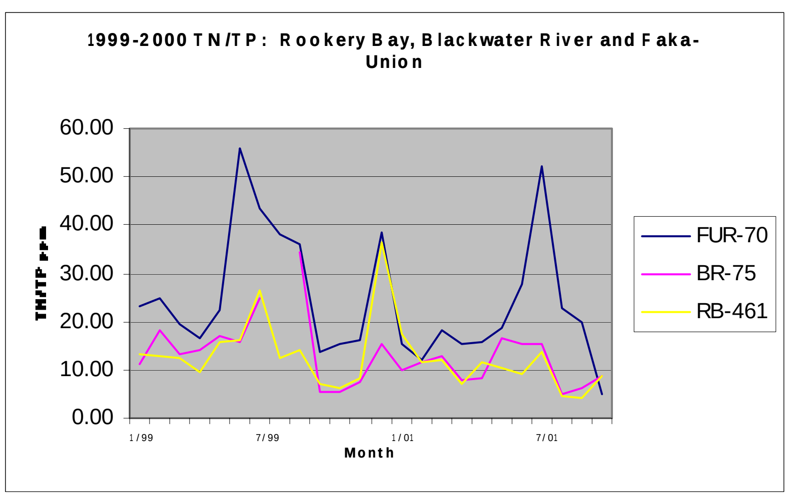
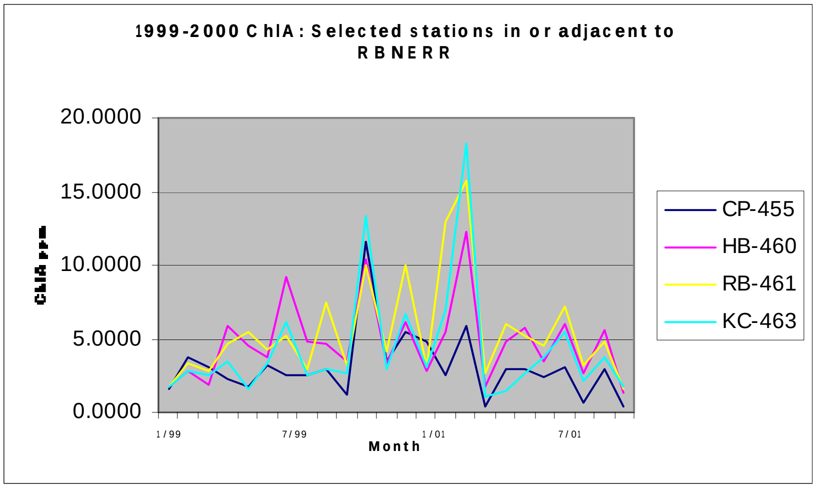
1/99
7/99
1/01
7/01
Month
PK-68
FUR-70
BR-75


1999-2000 TN/TP: Rookery Bay, Blackwater River and Faka-Union
TN/TP ppm
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1/99
7/99
1/01
7/01
Month
FUR-70
BR-75
RB-461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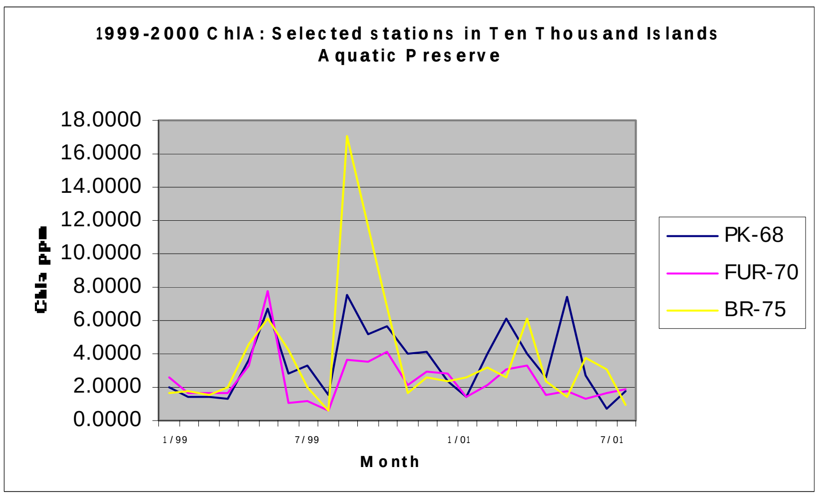
20.0000
15.0000
10.0000
5.0000
0.0000
ChlA ppm
1/99
7/99
1/01
7/01
Month
CP-455
HB-460
RB-461
KC-463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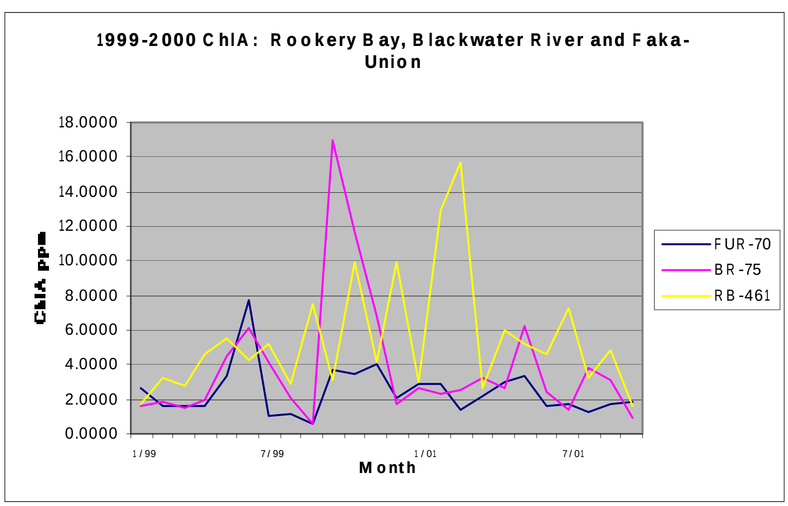
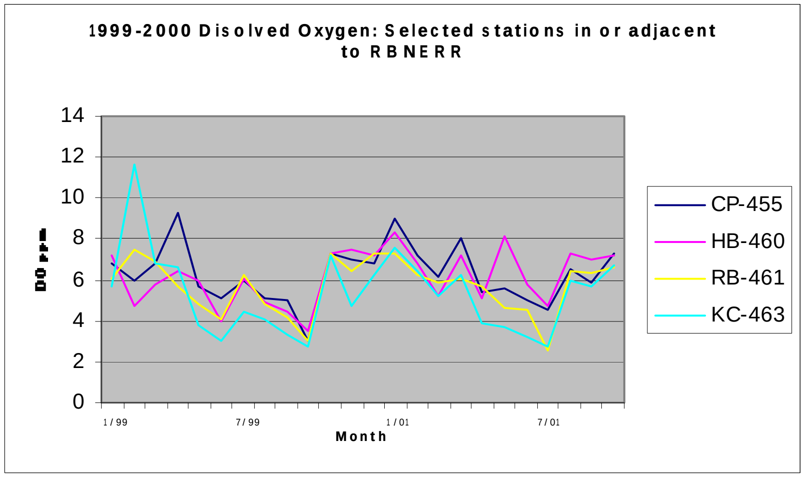
18.0000
16.0000
14.0000
12.0000
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
Chla ppm
1/99
7/99
1/01
7/01
Month
PK-68
FUR-70
BR-75


1999-2000 ChlA: Rookery Bay, Blackwater River and Faka-Union
18.0000
16.0000
14.0000
12.0000
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
ChlA ppm
1/99
7/99
1/01
7/01
Month
FUR-70
BR-75
RB-461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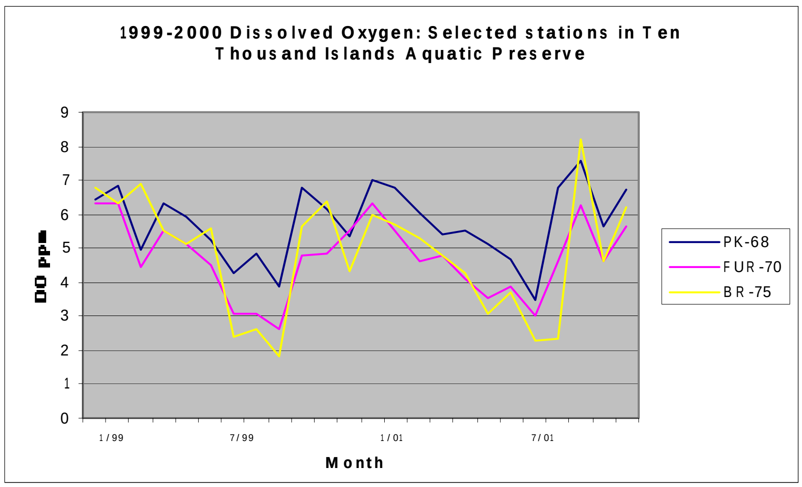
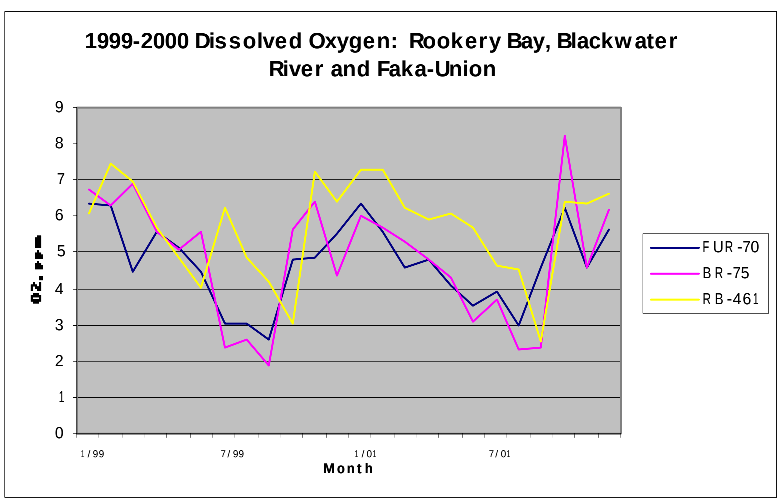
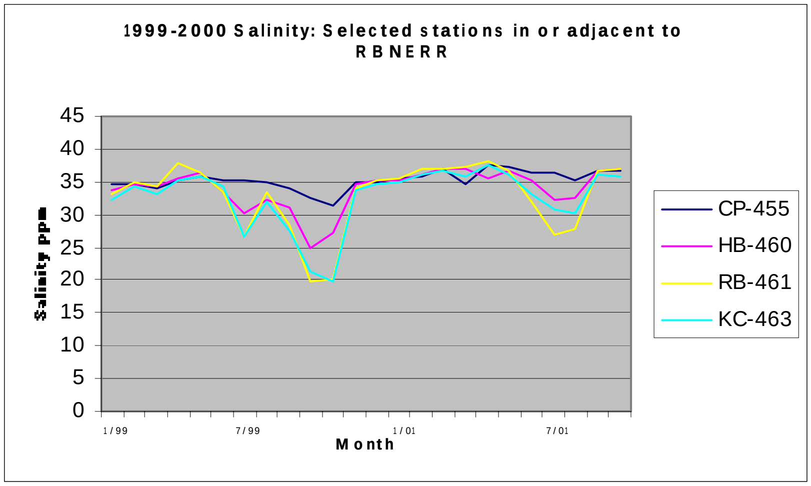
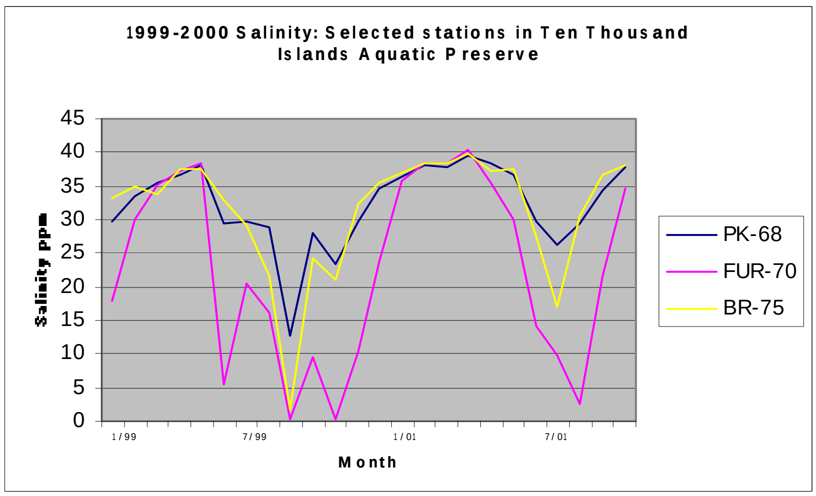
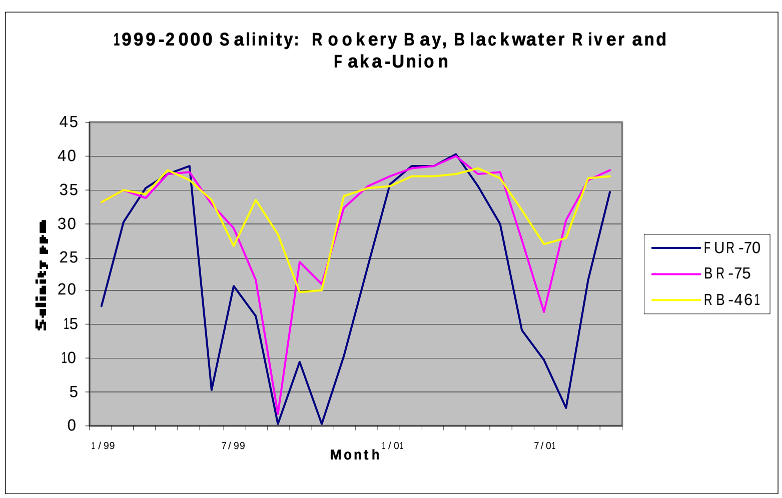
DO ppm
Month
CP-455
HB-460
RB-461
KC-463


1999-2000 Dissolved Oxygen: Selected stations in Ten Thousand Islands Aquatic Preserve
DO ppm
Month
PK-68
FUR-70
BR-75


1999-2000 Dissolved Oxygen: Rookery Bay, Blackwater River and Faka-Union
O2, ppm
Month
FUR-70
BR-75
RB-461


1999-2000 Salinity: Selected stations in or adjacent to RBNERR
Salinity ppm
45
40
35
30
25
20
15
10
5
0
1/99
7/99
1/01
7/01
Month
CP-455
HB-460
RB-461
KC-463


1999-2000 Salinity: Selected stations in Ten Thousand Islands Aquatic Preserve
Salinity ppm
45
40
35
30
25
20
15
10
5
0
1/99
7/99
1/01
7/01
Month
PK-68
FUR-70
BR-75

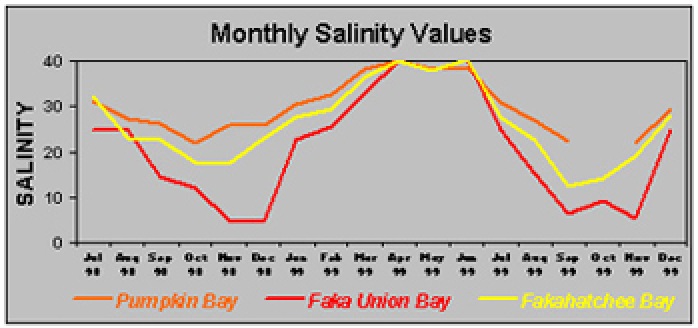

1999-2000 Salinity: Rookery Bay, Blackwater River and Faka-Union
Salinity ppm
45
40
35
30
25
20
15
10
5
0
1/99
7/99
1/01
7/01
Month
FUR-70
BR-75
RB-461

Effects Of Altered Freshwater Inflow On Fish, Shrimp And Crabs Of The 10,000 Islands Estuary Of Southwest Florida

Pumpkin Bay, Faka Union Bay and Fakahatchee Bay lie downstream of the Southern Golden Gate Estates, a failed development that built 813 miles of roads and 138 miles of canals during the 1960's to drain the swamps of Collier County in SW Florida. Over-drainage through the Faka Union Canal has resulted in a permanent 8-12 ppt salinity decrease in Faka Union Bay compared to adjacent Pumpkin and Fakahatchee Bays. Canals and roads in the Southern Golden Gate Estates, will be removed in 2001 providing a more even distribution of water to the three bays. In July 1998, we began a stratified, random, fisheries-independent trawling program to establish current baseline distributions and relative abundances of fish and invertebrates prior to the restoration. The planned hydrologic restoration will reduce the flow out of the Faka-Union Canal by 99% and provide a more even distribution (sheet flow) of water to the coastal wetlands and bays of the 10,000 Islands. Runoff from natural watersheds (without canals) is less variable and more sustained than flow from channelized wetlands (with canals) like the Southern Golden Gate Estates. Channelized flow creates extreme and abrupt salinity changes and reduces the area of estuarine essential fish habitat.

Materials and Methods

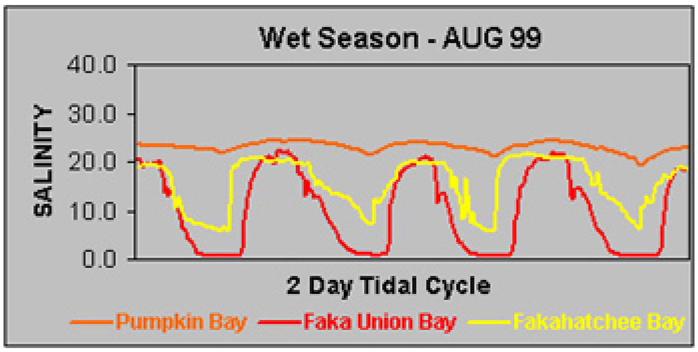
Sites were selected randomly in grids positioned downstream of the freshwater sources. Bottom trawls, using a 20ft. trawl with 1/8" mesh at each site covering approximately 0.1 nm, were deployed for five minutes. All fish were identified and measured (SL), as are pink shrimp(CL) and blue crabs(CW). Protocols were based upon the Florida Marine Research Institutes Fisheries Independent Monitoring Program. Volunteers were trained in fish identification and trawling protocols and were essential to this projects success.

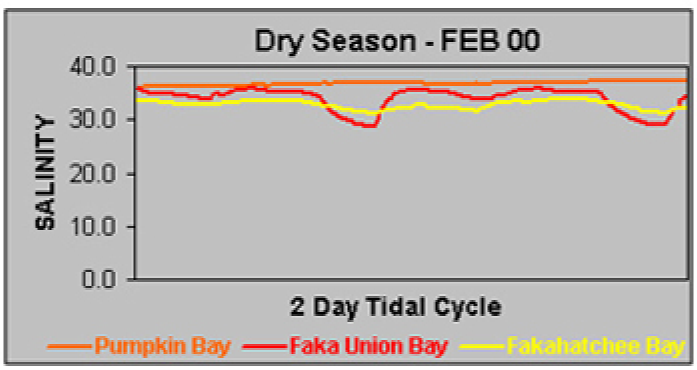


Results

Pumpkin Bay has the highest overall salinity and the lowest amplitude of fluctuation. Faka-Union Bay has the lowest overall salinity most of the year, but exhibits the highest level of fluctuation, with rapid salinity changes following significant rain events. Fakahatchee Bay lies between the two other bays in salinity, and exhibits a less pro-nounced fluctuation than Faka-Union.

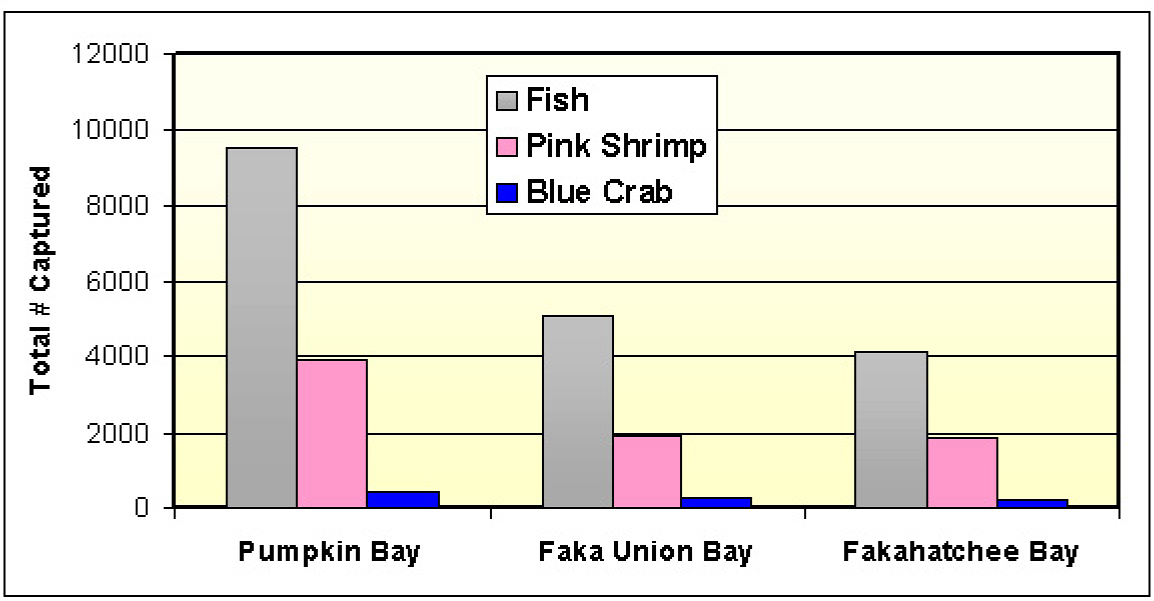
Pumpkin Bay has the highest overall species captured count. Pumpkin Bay also has the highest capture rate of *Gobiosoma robustum* and lower counts of *Microgobius gulosus* and *Microgobius thalassinus* than the other two bays.

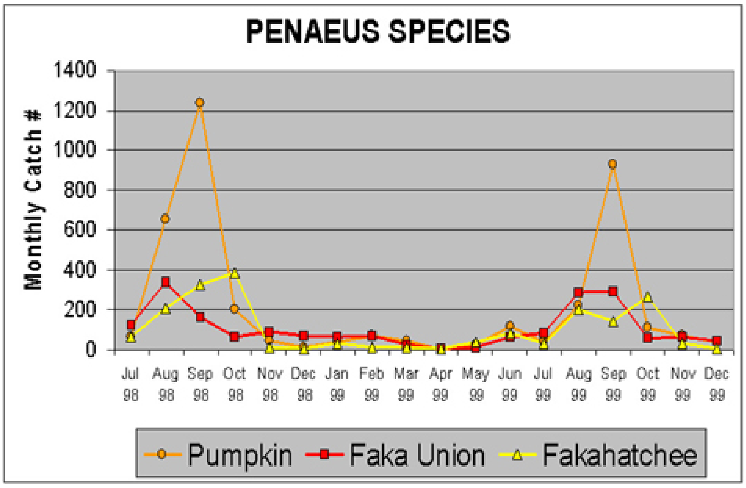


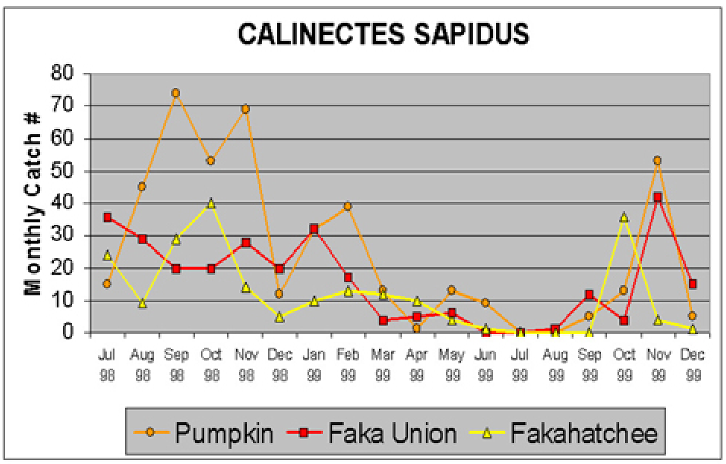


Discussion

All three bays have significantly different daily and annual salinity regimes. Pumpkin Bay has the lowest level of salinity fluctuation and Faka-Union has the highest level. The largest monthly catches for all bays occur during the end of the wet season (Aug - Nov). but Pumpkin Bay monthly catches are 2-4 times greater than the other two bays during the wet season. Faka-Union Bay has become a point source for freshwater in a saltwater system, while the watershed draining into Pumpkin Bay has had overland flow



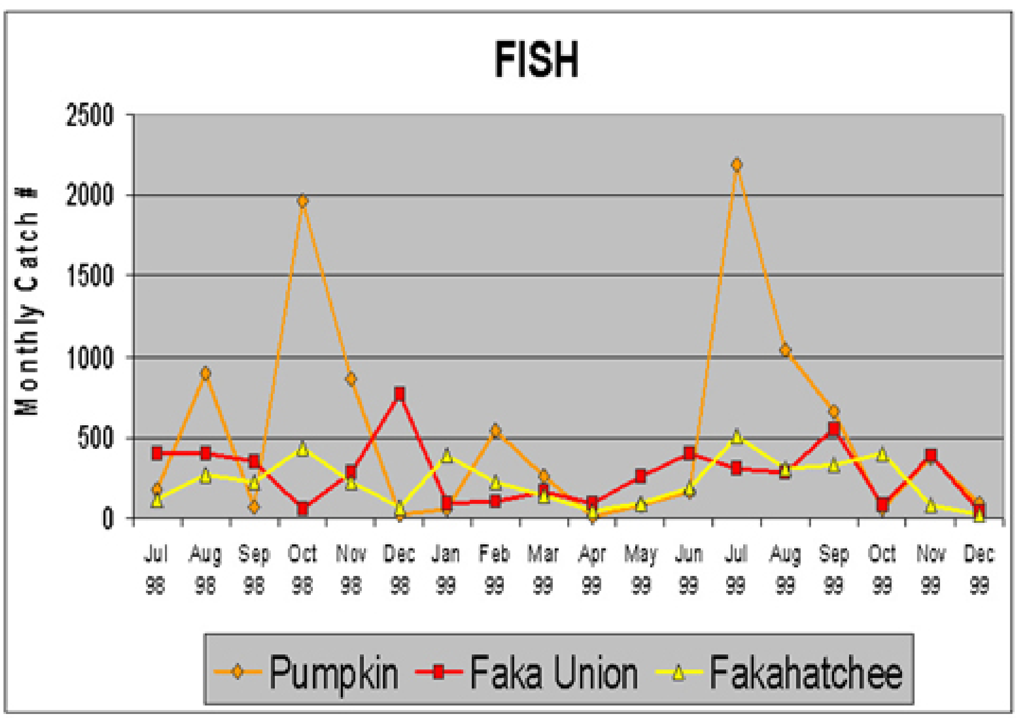


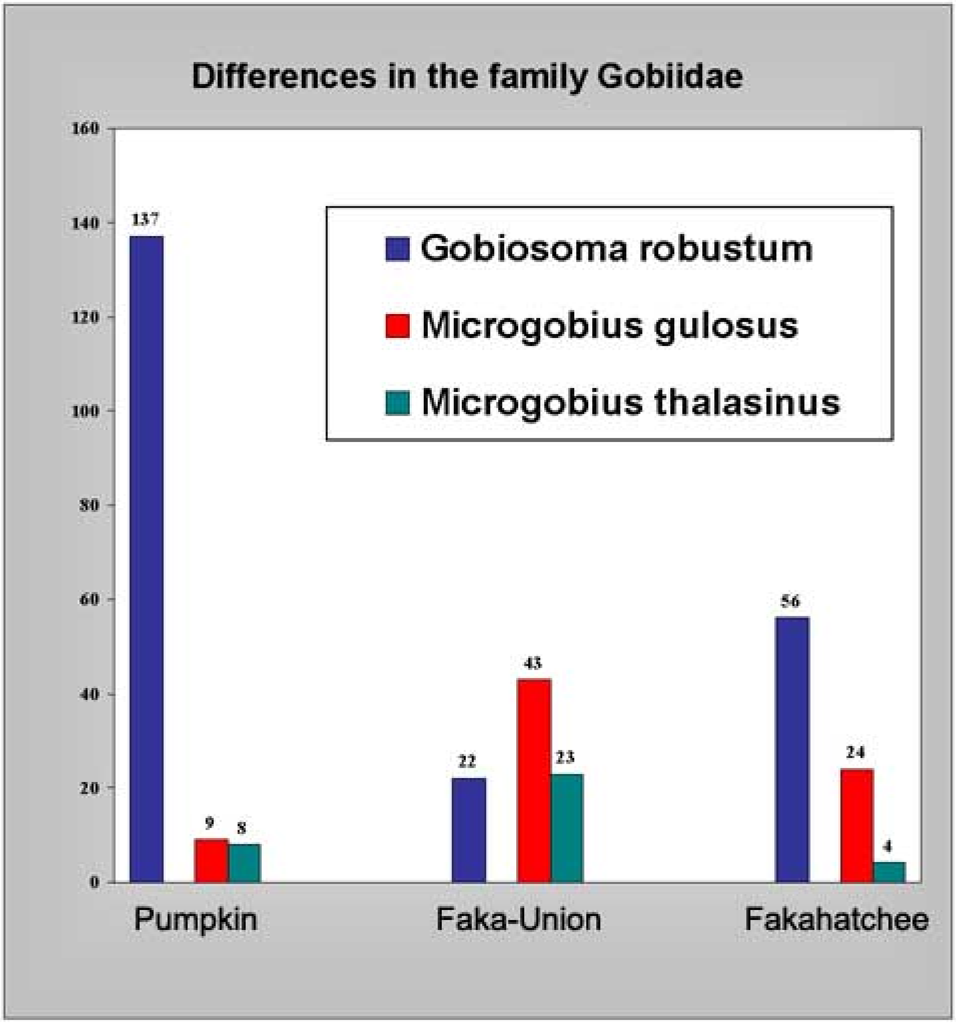


channeled into canals. Fakahatchee Bay has the lest affected watershed of the three studied.

Species specific differences in abundance are demonstrated by three goby species. These differences might make these gobies good indicator species.
Gobiosoma robustum (code goby) prefers higher salinities, seagrass beds and algal mats. Pumpkin Bay and Fakahatchee Bay exhibit higher salinities with more algal bycatch and a potentially higher number of code goby.
Microgobius gulosus (clown goby) and Microgobius thalassinus (green goby) prefer muddy bottom types. Faka Union Bay exhibits lower salinities with less algal bycatch and appears to have less consolidated bottom, with potentially higher number of clown and green gobies.

This study has been in progress for about three years, and will continue as a long-term monitoring project. Although this study was primarily intended to provide baseline data for the Southern Golden Gates Estates restoration, other bays will be added as time and staffing permits. Rookery Bay was added as a trawl site last year.




Differences in the family Gobiidae
160
140
120
100
80
60
40
20
0
137
9
8
22
43
23
56
24
4
Gobiosoma robustum
Microgobius gulosus
Microgobius thalasinus
Pumpkin
Faka-Union
Fakahatchee

Influence Of Altered Freshwater Inflow On Estuarine Crab Populations

Figure 1. *Eurypanopeus depressus*, a euryhaline crab.

Figure 2. *Petrolisthes armatus*, a stenohaline crab.

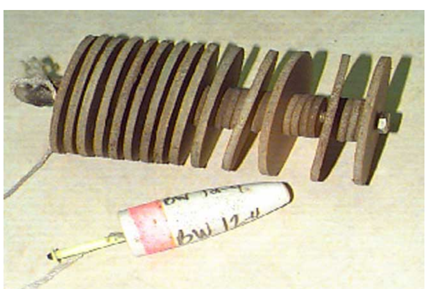


Figure 3. A Hester Dendy artificial substrate sampler.

Figure 4. A YSI datalogger used to record habitat salinity.

Management of freshwater inflow has altered the natural salinity of Henderson Creek. The observed salinity pattern coincides with a typical schedule of water release from the Henderson Creek weir, but not a natural pattern as exhibited by Blackwater River selected as the reference estuary. In the late dry season and early rainy season, water is held back at the Henderson Creek weir to prevent salt water intrusion. During this time, Blackwater River experiences greater salinity fluctuations than Henderson Creek. During the late rainy season, water is rapidly released into Henderson Creek in response to flooding within the watershed. This water release sometimes continues into the early part of the dry season. During these times, Henderson Creek experiences greater fluctuations in salinity than Blackwater River.

Estuarine species respond to seasonal changes in freshwater input which signal important life cycle stages such as reproduction and migration patterns. Although these species are naturally adapted to salinity fluctuations, some species are better adapted (euryhaline) than others (stenohaline) to tolerate these fluctuations. The two species chosen for these studies exhibit different salinity tolerances. *Eurypanopeus depressus* (Figure 1) is a euryhaline crab and *Petrolisthes armatus* (Figure 2) is stenohaline crab. These crabs are common inhabitants of oyster reefs. Once they recruit to a reef, they must remain and tolerate habitat conditions in order to survive. These species are also known to be important items in the diet of fish and birds.

METHODS

The crab populations of two oyster reefs within Blackwater River and Henderson Creek were monitoring by placing five artificial substrates (Hester Dendys, Figure 3) at each reef. Each month, after 14 days of deployment, the Hester Dendys were recovered, disassembled and their contents were collected on a 1mm sieve. All *Petrolisthes armatus* and *Eurypanopeus depressus* collected were counted and measured. In addition, the egg bearing (gravid) status of female crabs was recorded. Crabs with carapace widths measuring less than or equal to 5 mm were categorized as post larval stage and crabs with carapace widths greater than 5 mm were categorized as post juvenile.

Salinity (as parts per thousand, ppt) within Blackwater River and

Henderson Creek was monitored hourly using YSI data loggers (Figure 4). The loggers were maintained according to standard protocol recommended by the manufacture..

RESULTS

- There were significant seasonal and site specific differences in the salinity patterns of Henderson Creek and Blackwater River (Figure 5). In the late dry season and early rainy season, the Blackwater River exhibits greater salinity fluctuations than Henderson Creek. By late rainy season, and through the early dry season, this pattern is reversed.
- Season and location also significantly affected the abundance and condition of the crab populations. *Petrolisthes armatus* were not as successful at colonizing and maintaining a stable population within Henderson Creek as the more salinity tolerant species, *Eurypanopeus depressus* (Figures 6).

- Both species exhibited a seasonal pattern to reproduction and the recruitment of larval (post larval crabs) (Figure 7) and mature crabs (post juvenile crabs) (Figure 8) to artificial substrates. Egg bearing (gravid) crabs were collected most often during the summer months (June through September) (Figure 8) and the recruitment of post larval stage crabs peaked from July to October (Figure 7).

- There were significantly fewer egg bearing *Petrolisthes armatus* collected from Henderson Creek relative to Blackwater River (Figure 7). There were also significantly fewer larval *Petrolisthes armatus* recruiting to Henderson Creek (9). Mature *Petrolisthes armatus* were also significantly less abundant in Henderson Creek (Figure 7).

- Although there were fewer gravid *Eurypanopeus depressus* collected in Henderson Creek (Figure 8), the abundance of post larval (Figure 7) and post juvenile crabs (Figure 9) was similar to samples that were collected from Blackwater River.

- The ratio of post juvenile *Petrolisthes armatus* to post juvenile *Eurypanopeus depressus* at both locations provided a useful standard of comparison (Figure 9). These monitoring results indicate

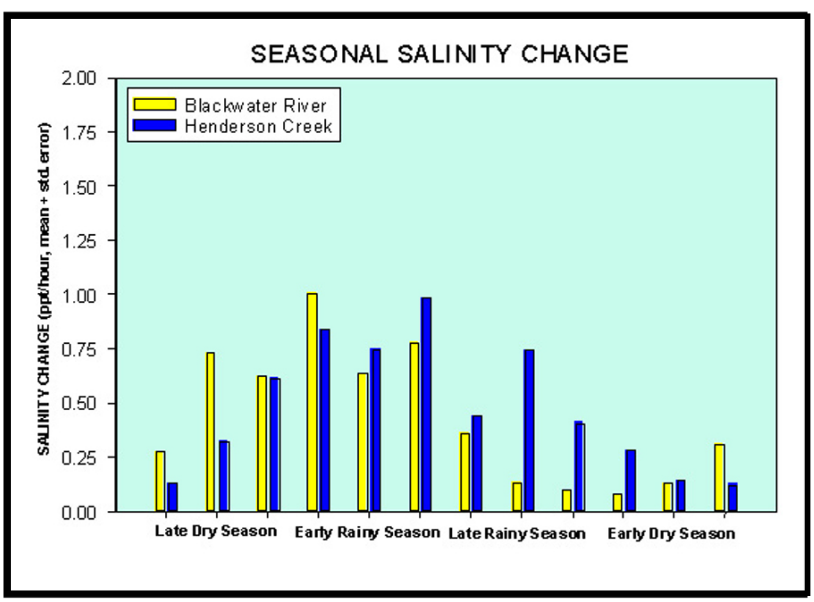


Figure 5. A comparison of the hourly salinity change for Blackwater River and Henderson Creek by season

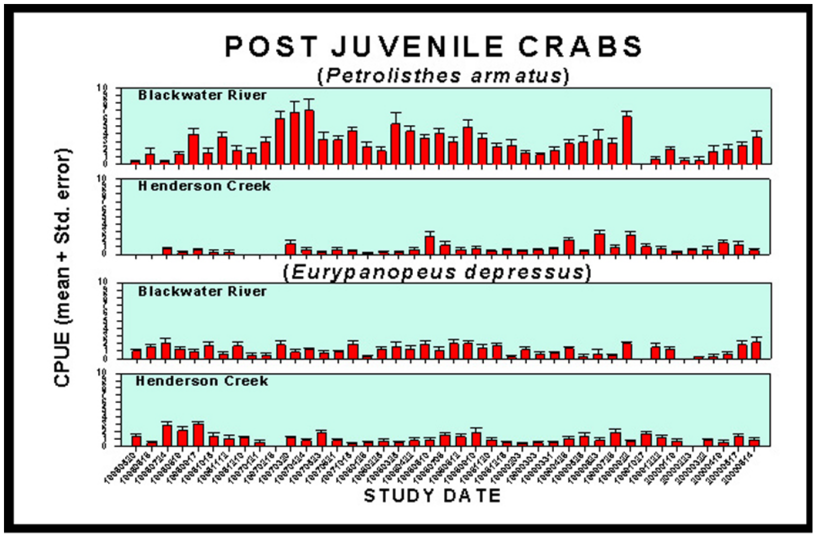


Figure 6. The abundance of post juvenile (mature) stenohaline (*P. armatus*) and euryhaline (*E. depressus*) crabs as affected by date and location.

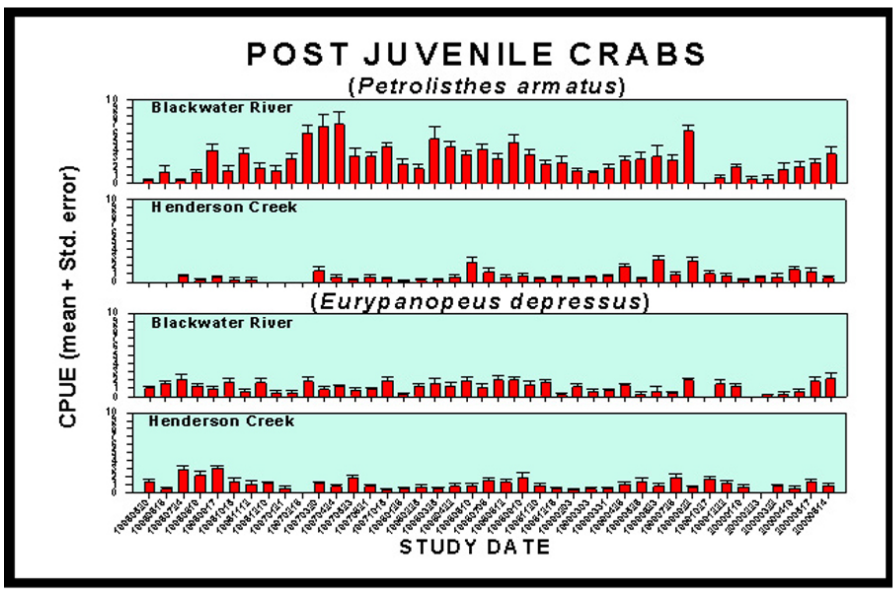


Figure 7. The recruitment of stenohaline (*P. armatus*) and euryhaline (*E. depressus*) post larval crabs to the oyster reef habitats as affected by date and location.

DISCUSSION

Estuarine species have evolved to respond to natural seasonal patterns of salinity change to guide important life history events such as reproduction and larval dispersal. Corresponding to the altered salinity patterns, we observed significant differences in reproduction, recruitment and population stability of estuarine crab species between Blackwater River and Henderson Creek.

In order to restore the freshwater inflow pattern to a more natural condition, the Reserve has received a grant through the National Marine Fisheries Service to finance a retrofit of the Henderson Creek weir to allow for a more gradual release of freshwater into the estuary. Based on these studies, the goal of this future restoration will be to release more water at the Henderson Creek weir early in the rainy season in order to reduce the need to release large amounts late in the rainy season in response to flooding in the watershed. Further research is needed to fine-tune this water release strategy to improve estuarine habitat while maintaining adequate flood control and the prevention of saltwater intrusion.

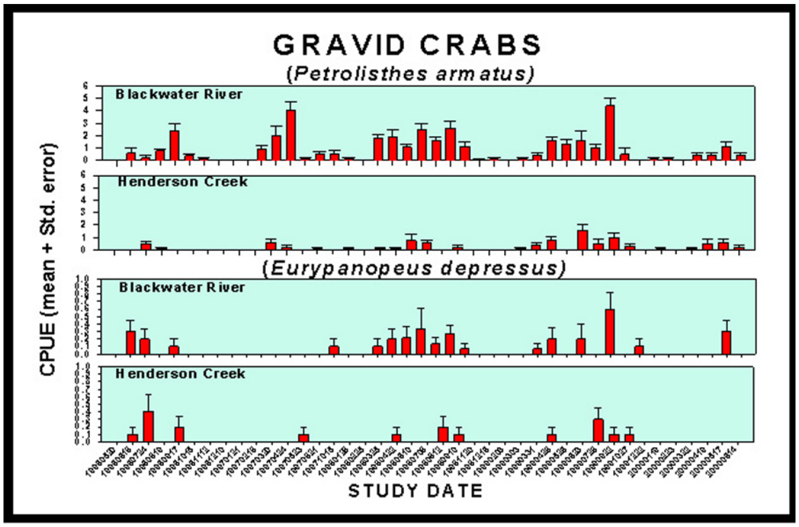


Figure 8. The abundance of gravid (egg bearing) of stenohaline (*P. armatus*) and euryhaline (*E. depressus*) crabs as affected by date and location.

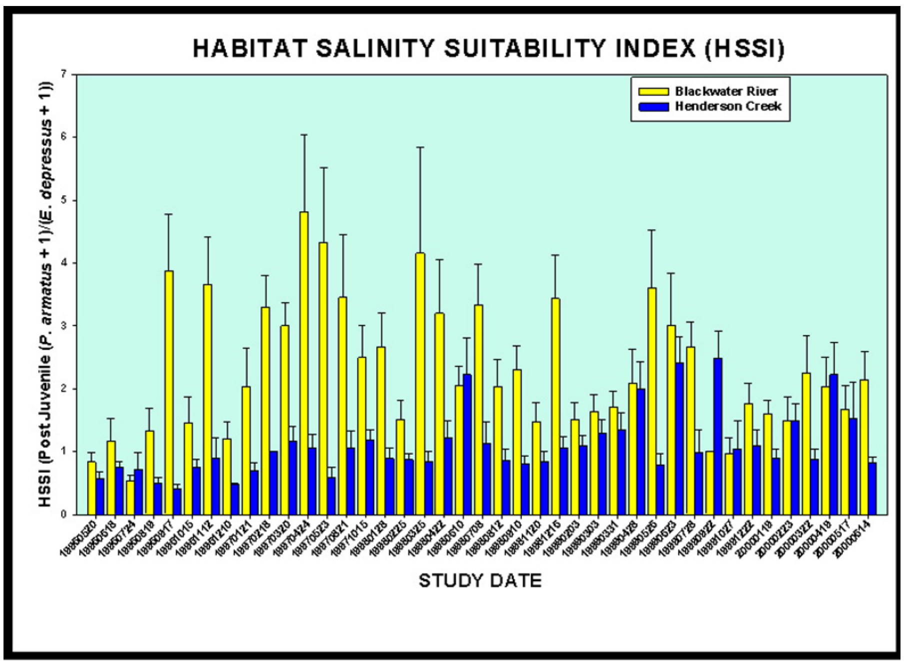


Figure 9. The relative abundance of stenohaline (*P. armatus*) and euryhaline (*E. depressus*) post juvenile (mature) crabs as affected by date and location.

ACKNOWLEDGEMENTS

These studies were funded by grants from the National Oceanographic and Atmospheric Administration's National Marine Fisheries Program and the Florida Department of Agriculture and Consumer Services' Coastal Zone Management Program. Funds were also provided by the Florida Department of Environmental Protection. Many individuals, past and present staff and volunteers from the Rookery Bay National Estuarine Research Reserve contributed to the success of these studies.

Loggerhead Nesting Before And After Australian Pine

Australian pines, *Casuarina equisetifolia*, were planted in southern Florida during the early 1900's, for protection against wind and storms (Craighead, 1971; Nelson, 1994). The shallow root system of this invasive exotic tree species makes them more susceptible to the effects of storm winds and erosion than native plants (Armentano et al., 1995). When they fall they may obstruct access to beaches by gravid female sea turtles (Schmelz and Mezich, 1988; LeBuff, 1990; Reardon, 1998). In March of 1998, Rookery Bay National Estuarine Research Reserve (RBNERR), Florida Department of Environmental Protection (FDEP), began a large scale restoration project to remove 250 acres of live Australian pines and snags from Keewaydin Island. Keewaydin Island, also known as Key Island, is a 12 kilometer, 1300 acre, primary barrier island off the coast of Naples, Collier County, Florida. Historically this island has been a significant nesting ground for loggerhead sea turtles, *Caretta caretta* (Addison et al., 1998). During the 1998 nesting season, Rookery Bay and the Conservancy of Southwest Florida began plotting the location of nests and false crawls via Global Positioning System (GPS), in order to document the effect of Australian pine removal on sea turtle nesting (Ryder et al., 2000)

Before Australian pine removal

After Australian pine removal

Methods

The Conservancy of Southwest Florida has been monitoring nesting activity on Keewaydin Island since 1982. Prior to each nesting season, the island was marked off into 500 foot increments with a surveyors wheel, which enabled nests and false crawls (FC) to be paced off to the nearest marker (Addison et al., 1998). A numerical location was recorded for each loggerhead emergence. Areas of the beach that were inaccessible due to fallen Australian pines were also documented each year. In 1998, after the Australian pine removal, The Conservancy of Southwest Florida and Rookery Bay NERR began recording the location of nests and false crawls via Global Positioning System (GPS). This data and future data will be mapped against the sections of beach where the Australian pines were removed. In addition yearly data on turtle morphometrics, clutch size, number of hatchlings to the gulf, and hatching success will be compared before and after the Australian pine removal.During the sea turtle nesting season of 2001, approximately 50 temperature data loggers will be placed in the middle of egg chambers while the sea turtle is laying the clutch. Each data logger location will be categorized as Australian pine present, Australian pine removed or Australian pines never present. A GPS location will be recorded to ensure data logger recovery. After the nest hatches, the incubation temperatures of the clutches will be compared among the three categories. A control temperature data logger will be buried in the sand in each of the three different areas throughout the duration of nesting season (May – October).

Preliminary Results

A comparison of loggerhead nesting activity before pine removal and after removal indicates an increase of activity in areas previously inaccessible. Although there is variability in total number of nests and false crawls before and after Australian pine removal, activity has increased in areas where fallen pines were removed (Table). Rookery Bay NERR and the Conservancy will continue monitoring Keewaydin Island over the following years. These data will be compared to the historical data (1990 - 1997) previously collected by the Conservancy. The results of this study will determine whether the removal of Australian pines alters nesting patterns. If these patterns shift as a result, the value of Australian pine removal as a management strategy on nesting beaches will be established.

In order to prevent further decline of threatened and endangered species of sea turtles, it is essential to understand how environmental conditions, such as beach altering activities, affects nesting and hatchling success. This information can then be taken to land managers to ensure "best management practices" on coastal beaches and prevent further degradation of suitable nesting habitat. Natural processes such as erosion are unavoidable and can not be permanently stabilized however, the encroachment of human impact and spread of invasive plant species on beaches are factors that can be managed. Research has been conducted to identify impacts on sea turtle nesting beaches and means to alleviate these impacts are receiving further investigation. One growing impact is the invasion of Australian pines on sea turtle nesting habitat in southern Florida. The pines have been shown to decrease sand temperature, which may affect the sex of hatchlings, and snags have greatly reduced the availability of suitable nesting beach. By comparing the historic loggerhead turtle nesting data on Keewaydin Island to the data collected after the pine removal, we will obtain a better understanding of how Australian pines impact nesting beaches. Furthermore, the results of this study will also determine whether their removal alters nesting patterns. If these patterns shift as a result, the value of Australian pine removal as a management strategy on nesting beaches will be established.

Loggerhead sea turtle nesting activity on Keewaydin Island, Florida. (FC - false crawl, AP- Australian pine, N/A - not applicable). Data courtesy of The Conservancy of Southwest Florida.

	Year	# FC on site	# Nests on site	Total FC	Total Nests	# Hatchlings
	1990	NA	NA	236	136	8546
	1991	3	1	292	191	10888
	1992	2	1	141	114	4770
	1993	10	3	194	156	6567
	1994	10	12	292	221	14145
	1995	7	2	274	178	4521
	1996	39	12	232	191	11824
	1997	15	11	244	180	12629
Australian pine removal	1998	111	42	404	269	16655
	1999	59	38	222	165	11167

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Acknowledgements

The Australian pine removal project was made possible through funding by National Marine Fisheries Service and DEP's Bureau of Invasive Plant Management. The Conservancy of Southwest Florida's Sea Turtle Monitoring Project on Keewaydin Island is funded by Conservancy members and donations.

*B*ird Monitoring

The National Audubon Society and its Collier County chapter have been active in preservation activities related to Rookery Bay and throughout the county for decades. Dr. Theodore H. Below, National Audubon Society warden biologist, has been monitoring bird populations and activities in Rookery Bay and surrounding coastal areas since 1972. With the help of RBNERR staff and local volunteers, tagging and counts of several species have been conducted throughout the Reserve.

Species of special interest are the Florida scrub-jay, translocated here in 1989 from the Archibold Biological Station in central Florida, and least terns, an endangered species due to loss of unpopulated sandy beach. Other birds monitored in the area include osprey, brown pelicans and gulls.

Florida Scrub-Jay Translocation

Few North American birds are as sedentary or habitat dependent as the Florida scrub-jay (*Aphelocoma coerulescens*). Scrub-jays live only in oak (*Quercus* ssp.) scrub, a fire-dominated shrub community unique to peninsular Florida and found only on well-drained sandy soils (Woolfenden and Fitzpatrick, 1960). This unique habitat is rapidly being converted to citrus groves, improved pasture and residential development, resulting in extensive habitat reduction and fragmentation. The subsequent suppression of the natural fire regime adds to lower quality habitat that cannot support scrub-jays and other scrub-dependent species. Large tracts of oak scrub, along with the Florida scrub-jays it supports, are rapidly disappearing.

Since 1969 all aspects of the biology and natural history of the Florida scrub-jay have been intensively studied (Woolfenden and Fitzpatrick, 1996). In 1987, due to declining numbers, the U.S. Fish and Wildlife Service listed this species as Threatened. In 1989, a study by Mumme and Below was initiated at RBNERR to evaluate translocation as a technique for restoring the Florida scrub-jay to unoccupied portions of its historic range. The goals of this study were to determine the long-term viability (pros and cons) of the translocation of Florida scrub-jays as a resource management technique; to develop translocation field techniques; and to generate detailed data on the population dynamics of a small, isolated, reestablished colony.

In 1989, 1990, and 1995, a total of twenty Florida scrub-jays were brought from Archibold Biological Station in central Florida and released into suitable scrub habitat at RBNERR. The effects of translocation, population dynamics, duration of residency and nesting success of these birds and their descends were followed until 1997 when the study ended. Mumme and Below (1999) concluded translocation, under certain circumstances, is a viable technique for restoring the threatened Florida scrub-jay to unoccupied portions of its historic range but is not an acceptable substitute for the management of existing populations (Mumme and Below, 1999).
The remaining Florida scrub-jay population at RBNERR is continuing to be monitored at RBNERR by Below for nesting success and survivorship. Because they habituate easily to humans and live in open habitat, Florida scrub-jays are excellent subjects for virtually all aspects of avian biology (Woolfenden and Fitzpatrick, 1996).

A conservation plan must incorporate both habitat protection and judicious fire management (Fitzpatrick et al. 1991). Maintaining scrub habitat in its native condition through prescribed burns is essential for keeping scrub in natural condition and suitable for Florida scrub-jays and other scrub-dependent species.

Osprey Productivity

Ospreys (*Pandion haliaetus*) are found worldwide, on every continent except Antarctica, and are a common breeding resident in coastal Collier County (Below, 1997; Stevenson, 1994). When nesting, ospreys are highly adaptable, building large, stick nests on both natural and artificial nest sites, including channel markers, power poles and specially built nesting platforms. During the 1950s and 1960s, pesticide contamination threatened many osprey populations. Egg viability fell drastically, depressing hatching rates and eventually breeding numbers as well. Today, these populations are recovering. (Poole, 1989). Historically, there was little monitoring of osprey populations in this region other than casual observation (Westall, 1983).

An osprey breeding productivity study, begun at RBNERR in 1984, records the number of nests and number of fledglings produced each season by ospreys in southwest Florida.
The goals of this study are to provide baseline data on the size and composition of the local osprey population, document annual fluctuations within this population and determine annual nesting trends, nesting productivity (fledges per nest) and nesting success by nest structure and location (manmade vs. natural).

Regular censuses are conducted by boat during the breeding season along three transects, totaling 70.6 km. The study area is made up of estuarine bars, creeks, mud flats, beaches, sandbars and mangrove islands. During these censuses, osprey nests are checked for nesting activity, number of eggs, number of chicks and number of fledged young. Collected data is analyzed for productivity and compared over time. Data indicates the osprey population in this area is resident and non-migratory with no influx of ospreys from outside the area during the winter months. Since 1984, osprey productivity indices average slightly above replacement and the population is increasing (Below, unpublished data).

Least Tern Nesting

The least tern (*Stern antillarum*) is listed as a threatened species by the Florida Game and Fresh Water Fish Commission (FGFFC, 1997) and protected by the Florida Endangered Species Act and the Federal Migratory Bird Treaty Act. They are summer visitors, arriving in Florida in mid-April to breed and raise young and leaving in August to migrate south for the winter. Least terns nest together in loose colonies on open sandy beaches and sandbars and depend on these breeding sites for their continued survival. Local colonies are subjected to severe summer storms with strong winds and flooding, often threatening and sometimes destroying the terns' reproductive effort for the season. Waterfront development, boat traffic and recreational beach use is increasing in Southwest Florida and presents another threat for least terns. Beaches and sandbars used for nesting that were once isolated are now teeming with beach goers.

A least tern productivity study was begun in 1982 and local tern colonies have been monitored regularly during the summer breeding season (Below, 2000). In April 2001, Rookery Bay National Estuarine Research Reserve (RBNERR), in cooperation with the Florida Fish and Wildlife Conservation Commission and the local Audubon Society, initiated the closure of an important least tern nesting sandbar located within RBNERR managed lands. This emergent sandbar, near Cape Romano, is posted as a "No Landing" area in order to protect least terns from human disturbance during their critical breeding season. Adult terns, tern nests and chicks are monitored weekly to determine seasonal nesting success and assess population trends and all species are noted (Below, 2000).

Least tern nesting sites frequented by humans often suffer from disturbance. Closing these areas during the breeding season, increasing law enforcement awareness, increasing public education, and installing informational signs and symbolic fencing will help to reduce negative human impacts on tern breeding success. Because least terns are relatively long-lived, survey numbers show delayed response to reproductive problems in the population, therefore it is important to monitor not just numbers, but also reproductive success (Thompson et. al., 1997).

Gulls, Terns and Shorebirds

Over fifty species of shorebirds, gulls, terns and skimmers (Families: *Charadriidae*, *Haematopodidae*, *Recurvirostridae*, *Scolopacidae*, and *Laridae*) occur annually at Southwest Florida coastal habitats as breeders, migrants or winter residents. For some of these species, 75% of their life cycle is spent at migrant stopovers and wintering sites and far less is known about this time in their lives (Paul, 1991). Shorebirds, gulls, terns and shimmers are highly dependent upon coastal eco-systems and have limited alternatives should these habitats be lost or degraded (Paul, 1991; Below, annual reports).

An ongoing population study of shorebirds (Family: *Scolopacidae*) and their allies was begun in 1982. Monthly censuses are conducted by small boat at high tide from Caxambas Pass, south of Marco Island, to Indian Key in the Ten Thousand Islands. This census focuses on shorebirds, but data is collected on all coastal birds using this area, including number and numbers of species, seasonal population fluctuations, and roost site availability and usage (Below, annual reports). Results of this census demonstrate shorebird population change over time compared to other bird species and can be used to evaluate the effects of human impact on environmentally sensitive areas, habitat protection needs, and the needs of threatened and endangered species. Periodic censuses of shorebirds have also been made in this area by the Florida Fish and Wildlife Conservation Commission (Sprandel, et. al., 1997)

A wintering shorebird population study, in cooperation with the Pan-American Shorebird Project, was conducted along 12 km of coast near RBNERR from 1985 to 1990. Approximately 1,200 individuals of sixteen species were captured and banded, and records have been kept of resighted marked individuals.

An education initiative to keep people from flushing shorebirds at foraging and resting sites, especially during spring and fall migration is needed. Weakened and vulnerable shorebirds with a reduced ability to feed may not be able to complete their migratory journeys.

Coastal Water bird Monitoring in Southwest Florida

Many species of water birds are highly dependent on coastal ecosystems and have limited alternatives should existing habitats be lost or degraded. Monitoring the relative changes within these species that depend on more specialized habitats should provide an indication of long-term changes in wetland conditions (Erwin and Custer, 2000, Chapter 15).

Reproductive success requires production, survival and recruitment into the breeding population of young birds. Safe nest sites and the quality of the surrounding feeding area are key requirements of breeding coastal water birds and their young (Hafner, 2000; Chapter 9). Most coastal water birds roost nightly in gregarious, multi-species groups at traditional sites. These roosts are important as both nesting and resting sites and must be protected from disturbance year-round.

National Audubon Society wardens began reporting on coastal water birds in southwest Florida in the mid-1930’s (Reiman, 1938). Since the mid-1970’s, water birds along the coast of southwest Florida from Naples Beach to Indian Key have been monitored along survey routes lying within RBNERR managed lands and adjacent state-owned lands. Numerous interconnected research projects have sprung from these surveys. Reports provided to RBNERR detail monitoring efforts and provide important baseline and long-term data sets (Below, annual reports; Doyle, pers. comm.). These reports aid coastal managers in making more informed decisions that affect both coastal water birds and their habitats.

Colonial Water bird Nesting

During the extended nesting season, December through August, coastal water birds (Families: *Pelecaniformes, Ciconiiformes* and *Charadriiformes*) are monitored along 37.5 miles of coast from Rookery Bay to Chokoloskee Pass (Below, annual reports). This area includes two major water bird colonies: Rookery Bay Islands, located within RBNERR, and the ABC Islands, which lie just outside RBNERR managed land boundaries. The ABC Islands colony is ranked among the top one hundred wading bird colonies in Florida (Runde, 1990, Appendix G).

Both coastal and inland hydrology patterns influence the onset and success of the nesting season. Nest initiation and success at these two colonies are compared to a 36-year database of inland water levels, recorded at Corkscrew Swamp Sanctuary and at a coastal pond located within RBNERR (Below, annual reports). Nest counts are conducted within these colonies during the breeding season and nestling survival is closely monitored. The population trends (total numbers of birds, number of adults, number of nests and breeding productivity) of seventeen species of coastal water birds are summarized within these annual reports. Six species designated as Species of Special Concern by the Florida Game and Fresh Water Fish Commission (FGFWC, 1997) nest at colonies located in or near RBNERR managed lands: snowy egret (*Egretta thula*), little blue heron (*Egretta caerulea*), tricolored heron (*Egretta tricolor*), reddish egret (*Egretta rufescens*), white ibis (*Eudocimus albus*) and brown pelican (*Pelicanus occidentalis*).

Coastal Water bird Population Dynamics

In conjunction with this nesting study, a long-term colonial water bird population study adds to the baseline data available for RBNERR managed areas. Bi-monthly sundown censuses of birds flying into a nightly roost at the Rookery Bay Islands have been conducted since 1977 and monthly sundown censuses have been conducted at the ABC Islands since 1979. In 1998, a sundown fly-in census of a substantial night roost located on a small island in Pumpkin Bay. The numbers of each species using these night roosts provide a good indication of their overall population size within the area (Naples to Panther Key) both during and outside the nesting period (Below, pers. com.)

Brown Pelican Study

The Eastern brown pelican (*Pelecanus occidentalis carolinensis*) is listed as threatened in Florida (FGFWC, 1997). In 1973, brown pelican population study was initiated at the ABC and Rookery Bay Islands water bird colonies, and within nearby coastal/estuarine areas. The purpose of the project is to document changes in the local brown pelican population. Population composition by age class, population size trends, seasonal population fluctuations and any other relevant data is recorded. Additionally, a biweekly census focusing on brown pelicans and including all coastal water birds was begun in 1973 (Below, 1996).

Coastal development and its associated disturbance can reduce the value of or eliminate nearby areas brown pelicans depend on for foraging and loafing. Indirect effects, such as reduced water quality, increased turbidity, and alteration of estuarine salinities can also adversely affect brown pelican and many other coastal water bird populations (Rodgers et al.,1996). Local governments increasingly view beach renourishment projects as the primary means of maintaining, restoring, and upgrading beaches for public use. The impact of increased water turbidity on the feeding success of brown pelicans and six other coastal water birds was studied during a beach renourishment project on Marco Island from 1990 to 1991 (Below, 1991a; Below, 1991b).

Brown pelican populations appear to be increasing throughout much of their range (Rodgers et al., 1996). However, monitoring results show a continuing decline in the local population since 1984, not only in the overall number of individuals in all age classes, but also in the adult nesting effort (Below, 2001 pers. communication)

Recreational boaters, fishing guides, and eco-tourism operators often flush birds when they approach too near a rookery. During the nesting season, disturbed birds may knock eggs or young from the nest and prolonged human disturbance can cause adults to abandon their nests altogether, resulting in colony failure. Throughout the year, boats approaching too close to the roost at sundown can prevent incoming birds from roosting, causing birds to abandon the site or relocate to a less desirable location. Increased public education and law enforcement is needed. Entanglement in fishing line often leads to water bird mortality. This occurs when fishermen accidentally or intentionally discard large bunches of line or cut their lines when hooked on vegetation. This is especially critical at or near rookeries. Public awareness through environmental education and rookery “clean-ups” can help. Conservation attempts need to focus not only on breeding site protection, but also on large-scale habitat preservation near nesting colonies.

There is a direct correlation between heron population size and available habitat (Kushlan, 1978). Without adequate food supply and suitable feeding locations, heron populations decline.

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HABs

Harmful algal blooms (HABs) occur throughout the world, and have been increasing in occurrence, risk to human marine animal health, and impact on estuarine related economies in every coastal area of the United States (Culotta 1992, Baker 1998). Assessments by the National Fish and Wildlife Foundation partnered with NOAA (Boesch et al. 1997) concluded that areas of research requiring immediate attention related to these algal blooms are development of early warning systems and research supporting understanding and prevention of HABs. There is no clear cause and effect model for bloom occurrence. The most notable HAB in southwest Florida is “red tide”, large population pulses of *Gymnodinium breve*. *G. breve* blooms occur annually in the Gulf of Mexico, but have occurred as far north as North Carolina (Tester and Steidinger 1997).

Monitoring of *G. breve* is coordinated in the State of Florida by the Florida Marine Research Institute (FMRI), and volunteers collect samples at several points within RBNERR waters. Results of this project can be viewed at http:// www.floridamarine.org

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Research Needed

Water Quality
Watersheds
Wildlife
Estuarine Ecology
Restoration Science
Proposed Sites

As resource management issues come up at RBNERR, we look for the scientific research that provides clues to potential solutions. Science-driven management is a high priority, and by definition, RBNERR is a research preserve. Visiting investigators and graduate students provide much of this research, and this information on immediate research needs can be used both as ideas for project direction and as support for funding proposals. These projects outlined below are of special interest for RBNERR because they address objectives from the management plan.

Water Quality

Grabe (1993) examined a ten year dataset collected from1979 to 1989 and concluded that phosphorus, total nitrogen and inorganic nitrogen concentrations within the Henderson Creek watershed have increased. Grabe (1993) also found that Nitrogen to Phosphorus ratios decreased over this time period. These increases are not reflected in estuarine nutrient concentrations (Christensen, 1998) . More research is needed to determine the relative importance of nutrient input from mangrove forests relative to freshwater runoff and tidal export /import and sediment resuspension. Sampling of storm and tidal events is also needed to construct a more accurate nutrient budget.

Christensen (1998) found that, in general, nutrient concentrations were not consistently correlated to chlorophyll a concentrations. However, his analysis found a significant positive correlation between nitrate and chlorophyll a concentrations at three stations including lower Henderson Creek. More detailed studies of the association of light attenuation and nutrient dynamics are needed to determine the feasibility of setting nutrient runoff reduction goals for enhancing light penetration for enhancing and protecting seagrass habitats. A scientific evaluation of best management practices for stormwater treatment by golf courses, residential areas and agriculture is also needed to develop landuse recommendations to ensure that increasing watershed nutrient concentrations do not cause noxious algal blooms or increased hypoxia.

Recent information, being generated by the Reserve's staff using continuous water quality monitoring equipment, is providing insight into short-term fluctuations in salinity and the duration of hypoxia. Research is needed to understand the biological significance of these measured events. In addition, studies are needed to determine the influence of watershed landuse patterns on the biogeochemical conditions of estuarine systems managed by the Reserve to guide stormwater management strategies associated with flood control, aquifer recharge, irrigation, habitat restoration and development. Presently, watershed stormwater is managed primarily to reduce flooding and recharge aquifers. This management practice results in holding water in the watershed during periods of low rainfall and rapidly releasing water in response to flooding or an anticipated storm event. This water management strategy may alter natural salinity patterns within an estuary by delaying the onset of the seasonal salinity decrease to later in the rainy season, by prolonging the flow of freshwater into the early dry season and by intensifying hypersaline conditions during the late dry season. In addition, in extreme situations, increased freshwater inflow can physically prevent recruitment of organisms into an estuary. Research is needed to monitor estuarine habitats and organisms in response to watershed water management activities to determine the biological significance of altered quantities and patterns of freshwater inflow.

Watersheds

Little research beyond species inventories has been completed on the upland and freshwater communities within the Reserve and the Aquatic Preserves. Anecdotal information and intutitive theories about encroachment from mangroves due to saltwater intrusion exist. Further, research on communities similar to those in southwest Collier County does exist, however, the work has been completed in different geographic locations (north Florida or the more calcareous southeastern tip of the Florida peninsula). Consequently, the areas of research needed for the terrestrial portions of RBNERR are wide open.

Pine flatwoods, palm oak hammocks and scrub communities are of particular interest. Studies evaluating water tables, chloride concentrations, nutrient cycling, transpiration, fire intervals, invasive plant susceptibility, and groundwater movement would address key RBNERR management issues and assist in restoration efforts, as well as modeling of future development impacts on RBNERR's estuaries.

Preliminary work to assess the presence of residual pesticides in abandoned agriculture fields found high levels of Chlordane and varying levels of other organochlorine substances. More extensive surveys are needed to determine the full extent of residual toxins in areas of future development or restoration to avoid chronic and acute distress of estuary invertebrates, fish and wildlife.

Accurate assessment of groundwater levels will lead to better management of seasonal stormwater and residential retention areas. There are currently no monitored wells in the Reserve, and a limited number in the Belle Meade watershed. Wells in restoration areas, mangroves and saltmarshes are of particular interest. These same wells could be used to assess chloride concentrations in transects beginning at open water and ending east and north of US 41.

Wildlife

Research on bird populations has been conducted since the '60s by Dr. Ted Below, warden for the Audubon Society in southwest Florida. He is aided by local volunteers, and many of these assistants are available to assist with bird population studies. Because of these efforts, a large number of specific questions about bird behavior and responses have been identified.

- identifying and evaluating limiting factors affecting the size of least tern nesting colonies
- assessing the behavioral and demographic responses of least terns to an increase in human disturbance
- applied research projects exploring methods to maintain, enhance or expand existing least tern nesting habitat to promote increased breeding productivity
- banding projects addressing shorebird population overwintering patterns and wintering site fidelity
- the relationship of local invertebrate food resources, shorebird feeding regimes, and feeding disruption from human disturbance on shorebird surivorship prior to and during migration
- a study of the effects of coastal mosquito control spraying (timing, deposition levels, and pesticides) on shorebirds
- habitat relationships between nesting/roosting sites and feeding sites, incorporating watershed management issues
- degree of interspecific and intraspecific site fidelity to nesting/roosting islands and feeding sites and their adaptability to rapidly modified habitats
- breeding success by species, intraspecific and interspecific resource competition, energy needs, the relationship between breeding/fledgling success and food resource availability, and nesting seasonality
- effects of increased human disturbance at nesting/roosting sites on reproduction and survivorship
- evaluation of the potential threat of environmental contaminants found in coastal waterbird feeding areas associated with intensive agricultural activity, using the trace element contaminant concentration levels found in waterbird tissue, excrement or feathers
- possible correlations between coastal waterbird (terns and pelicans) feeding success and turbidity levels caused by beach renourishment by dredging

- determine the level of activity/disturbance from increased boat traffic that ospreys are able to tolerate at nest site locations and the effects of this disturbance on nesting success and productivity
- compare local osprey nesting productivity and survivorship with populations in Everglades National Park before, during and after the Everglades Restoration Project
- use ospreys as biological indicators by studying the impact of agricultural pesticide runoff on osprey reproduction and survival
- marking or tagging projects which would improve knowledge of osprey pair bond formation and duration, survivorship and additional life history data
- comparing annual food availability to osprey chick survival and fledgling success
- the relationship between scrub-jays and scrub habitat that is affected by humans (fire-suppressed, fragmented, fire-restored).
- comparing the established RBNERR, translocated, scrub-jay population with populations from both other translocation sites and historical sites to further evaluate this management technique.
- The energetic and physiological ecology of the Florida scrub-jay are little studied but could yield much insight into the age-and stage-specific costs of reproduction, molt, territory defense, helping behavior, and dispersal (Woolfenden and Fitzpatrick, 1996).
- mounting evidence suggests that Florida scrub-jays succumb to episodic arboviral diseases, but the overall importance of disease in their population biology (and conservation) is in need of further research (Woolfenden and Fitzpatrick, 1996). Especially so with the arrival of West Nile Virus in Florida in the summer of 2001.

Exploratory insect, reptile, amphibian and small mammal trapping has begun as part of the multi-species habitat database/modeling work. More intensive trapping is needed to determine population composition, size and distributions. Comprehensive biological/ecological studies of individual species or guilds of species is essential to understanding the role of fire and hydroperiod changes on RBNERR's wildlife. Fire and hydrologic restoration/conservation are key areas that resource management has some control over, and multi-species management is a RBNERR goal.

RBNERR is proactive in manatee rescue and release, and sightings are documented by RBNERR staff. However, a quantitative evaluation of population size, areas of refugia, and seasonal migration paths would assist in delineating manatee zones and avoidance of boating accidents.

Estuarine Ecology

Browder (1988) and others have hypothesized that the effects of canal discharge on the affected bays, such as Faka Union Bay, may be due to 1) reduction in the area of favorable salinity; 2) loss of important benthic habitats (esp. seagrass beds); 3) reduction in the recruitment of fish eggs and larvae; and 4) damage to benthic fauna. More research is needed to document these alterations and to determine mechanisms of, and the thresholds beyond which, this damage occurs. Ideally, baseline information should be collected prior to the planned watershed hydrologic restoration projects. Regrettably, despite these restoration efforts, the future management of watersheds of the estuaries managed by the Reserve is constrained by the competing needs for flood control, drinking water and irrigation. The question "What freshwater inflows does an estuary need ?" must be answered with a value that can be engineered into this complex water management equation.

A resurvey of the regions seagrass habitats to determine the extent of the loss of this habitat is also needed. A continuation of long-term oyster reef monitoring by the Reserve staff and visiting investigators is encouraged. The Reserve staff has recently established four coastal and four backwater seagrass habitat monitoring transects. Long-term monitoring of these study sites, along with ancillary data relating to factors affecting light attenuation, salinity fluctuation and eutrophication, will provide useful information to guide future management strategies. There is a need for additional research on understudied benthic habitats and processes, especially the role of macroalgae, sponge beds, oyster reefs, vermetid reefs, and salt flats as habitats and the role of benthic bacteria in carbon cycling of mangrove and macroalgae detritus.

Another intriguing question is the historic distribution of backwater seagrass habitats and benthic fauna. The development of paleobiological techniques to map historic seagrass and benthos along with an understanding of the factors limiting the distribution of seagrass and benthic fauna is needed to set goals for future restoration initiatives. Also needed is a greater understanding of the role of macroalgae as a habitat and food source for fish and macroinvertebrates.

The key to effective conservation of mangrove forest habitats is to develop methods that detect changes in forest health prior to mortality. Monitoring of sediment accretion rates in relation to sea level increases and land subsidence is one example of such a monitoring approach. Monitoring tools also need to be developed to provide early warning of forest degradation due to herbicide runoff from nearby golf courses, residential areas, and agriculture.

Studies are also needed to develop monitoring methods to examine the subtle changes in mangrove forests function and structure associated with anthropogenic effects such as nutrient enrichment, altered tidal exchange and changes in the amounts of freshwater inflow. Development of a technique based on remote sensing technology would be particularly useful for monitoring remote locations and large areas managed by the Reserve.

Additional studies are needed to link the function of overwash, fringe and basin mangrove forests to nutrient dynamics and water quality of Rookery Bay. This research should include estimates of atmospheric inputs of nutrients and their influence on mangrove forest productivity. In addition, more research is needed to quantify the rate of organic carbon exchange associated with below ground productivity (root turnover rate), along with anaerobic respiration of the forest floor.

Future studies are needed to quantify the link between mangrove forests and the secondary productivity of adjacent estuaries. In particular, the role of mangroves as habitats for recreational or commercially valuable species and as a basis of the detritus-based food web leading to these species needs to be empirically established. Experimental verification is needed of the assertion that mangrove forests are providing food to mobile estuarine consumers. The ecological role of dissolved organic matter exported from mangrove forests should also be further explored.

Quantitative measurement of the energy flow associated with the basin forest detritus-salt marsh mosquito food chain is needed. This information would have significant ramifications regarding future mosquito control issues and the impact of mosquito control on species dependent upon this pathway.

The significance of the export of decomposing woody debris, particulate organic matter and dissolved organic matter during and following a destructive storm to the organic export from mangrove ecosystems is another research priority. Given the historic frequency of large hurricanes in the area, the Reserve is overdue for a major storm. The opportunity is at hand to collect valuable baseline data regarding mangrove productivity.

Tests of mangroves as refugia remain to be conducted (Sheridan, 1997). Specifically, Sheridan (1997) identified the need for a comparative analysis of predation efficiency and prey selection in relation to the degree of tidal inundation for mangroves, non-vegetative mud and seagrass habitats. This research is needed to provide a more complete understanding of the relative functions and values of these habitats.

The removal or trimming of mangroves along private waterfront property is a common site in Southwest Florida. Mangroves provide significant protection to landward areas during hurricanes by mitigating the effect of waves. Wider areas of mangrove forest provide greater protection. Mangrove forests also trap sediments, thereby naturally reducing the rates of beach erosion. Further research is needed to document the value of mangroves as shoreline stabilizers to provide incentive to private and public landowners to restore and protect fringing mangrove forests.

Herbicides, nutrients, sediments and other pollutants in stormwater runoff, in addition to mangrove trimming, the drift and deposition of mosquito control pesticides, and alterations in freshwater and tidal exchange have cumulative impacts on mangrove forest structure and function. Studies are needed to quantify these effects to assist in the planning and prioritizing of resource management strategies. Mangroves can also act as a sink or source for heavy metals, polyaromatic hydrocarbons (PAH's), pesticides and nutrients. More research is needed to understand the effects of changing pH, salinity and hydroperiod on the mobilization of these materials. In addition, the exchange and bioaccumulation of these contaminants in fauna associated with mangrove forests or into those species that dependent upon the mangrove detritus-based food web needs further investigation.

Restoration Science

Restoration of new land acquisitions is an important RBNERR goal and covers a wide range of community types and hydrologic alterations. Due to limited staff and the process for obtaining and spending restoration funds, comprehensive monitoring and baseline studies are not always feasible. Because restoration often creates a short-lived transitional shock response followed by differing permanent communities, establishment of long-term monitoring projects is encouraged.

Opportunities to restore mangrove forests must be coupled with studies of habitat structure and function to guide future habitat restoration efforts. These studies would also serve to demonstrate the limitations of mangrove restoration as mitigation for loss of mature habitats elsewhere. The Reserve will encourage research efforts that can be used to standardize habitat restoration methods and monitoring protocol. Research into the factors influencing the spread of invasive exotic species, particularly Australian Pine (Casuarina equisetifolia) and Brazilian Pepper (Schinus terebinthifolius) into mangrove forests, also require further study.

Bibliography

An extensive body of research has been completed at RBNERR, both by staff and visiting investigators. Some of this is available in refereed journals and government reports available to the general public. However, a significant amount is available only as technical reports, dissertations, thesis and unpublished manuscripts. Further, a fair amount of the published work was completed in conjunction with other higher interest sites, making it difficult to locate references specific to Rookery Bay and the western Ten Thousand Islands.

This bibliography is a compilation of all research currently summarized for the Reserve, the Aquatic Preserve and their watersheds. The ProCite data file is included for the convenience of authors in need of citations. The entire bibliography is also available as a seperate PDF file.

All of the unpublished references will soon be available for review at Florida Gulf Coast University library, and, soon after that, available as full text on-line documents.